East Waterway Operable Unit

Final Feasibility Study – June 2019

EXECUTIVE SUMMARY

For submittal to the U.S. Environmental Protection Agency, Region 10, Seattle, Washington

Prepared by

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List of Acronyms and Abbreviations

μg	microgram
ARAR	applicable and relevant or appropriate requirements
BMP	best management practice
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CMA	construction management area
COC	contaminant of concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CSL	cleanup screening level
CSO	combined sewer overflow
cy	cubic yard
dw	dry weight
Ecology	Washington State Department of Ecology
ENR	enhanced natural recovery
ENR-nav	enhanced natural recovery applied in the navigation channel and deep-draft berthing areas
ENR-sill	enhanced natural recovery applied in the Sill Reach
EPA	U.S. Environmental Protection Agency
ESD	Explanation of Significant Differences
EW	East Waterway
EWG	East Waterway Group
FS	Feasibility Study
Hg	mercury
kg	kilogram
LDW	Lower Duwamish Waterway
mg	milligram
MLLW	mean lower low water
MNR	monitored natural recovery
MTCA	Model Toxics Control Act
NA	not applicable
ng	nanogram
OC	organic carbon
OU	Operable Unit
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PQL	practical quantitation limit
PRG	preliminary remediation goal
RAL	remedial action level
RAO	remedial action objective
RBTC	risk-based threshold concentration
RMC	residuals management cover
RME	reasonable maximum exposure
ROD	Record of Decision
SCO	sediment cleanup objective
SMS	Washington State Sediment Management Standards
SQS	sediment quality standard
SRI	Supplemental Remedial Investigation
SWAC	spatially-weighted average concentration
TBT	tributyltin
TEQ	toxic equivalent
UCL95	95% upper confidence limit on the mean

Overview of the East Waterway Operable Unit Cleanup

Site Description

The East Waterway (EW) is an Operable Unit (OU) of the Harbor Island Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Superfund site located in Seattle, Washington. The EW is a 1.5-mile-long, 157-acre maintained waterway in one of Seattle's primary industrial and commercial areas. The EW is located immediately downstream and north of the Lower Duwamish Waterway (LDW) Superfund site, along the east side of Harbor Island (Figure 1). The EW was created during the construction of Harbor Island in the early 1900s to serve developing industries and commerce in Seattle.

The EW is an estuarine environment in which the Green/Duwamish River discharges freshwater to Puget Sound. The EW is open to Elliott Bay on the north, and water levels are subject to a tidal range of approximately -4 feet mean lower low water (MLLW) to +14 feet MLLW. The water column in the EW is saltwater, with a surface lens of freshwater from the riverine discharge.

Purpose of the Feasibility Study

Under the oversight of the U.S. Environmental Protection Agency (EPA), this Feasibility Study (FS) has been conducted by the East Waterway Group (EWG), consisting of the Port of Seattle, the City of Seattle, and King County. The purpose of this FS is to develop and evaluate EW-wide remedial alternatives to address the risks posed by contaminants of concern (COCs) within the EW. Specifically, this FS:

- Summarizes the results of the Supplemental Remedial Investigation (SRI; Windward and Anchor QEA 2014[1]) including EW uses, nature and extent of contamination, and human health and ecological risk assessments
- Develops remedial action objectives (RAOs) and preliminary remediation goals (PRGs) that define the goals of the cleanup
- Develops physical and chemical models to predict concentrations of key COCs in sediment over time
- Delineates remediation footprints for cleanup using remedial action levels (RALs) for key COCs
- Evaluates and screens potential remedial technologies that could be used to clean up different areas of the EW
- Develops a suite of potential remedial alternatives for cleanup of the waterway
- Compares those alternatives based on the CERCLA remedy selection criteria

Supplemental Remedial Investigation

The SRI documents the results of a series of studies completed over 8 years, including the following:

- A conceptual site model
- Physical and biological interactions of the waterway system, including physical processes that affect sediment transport into, within, and out of the EW
- The nature and extent of contamination
- The risks that contamination presents to people and animals that use the EW

Contaminants of Concern

The primary COCs in EW sediments include polychlorinated biphenyls (PCBs), arsenic, mercury, dioxins/furans, and carcinogenic polycyclic aromatic hydrocarbons (cPAHs).

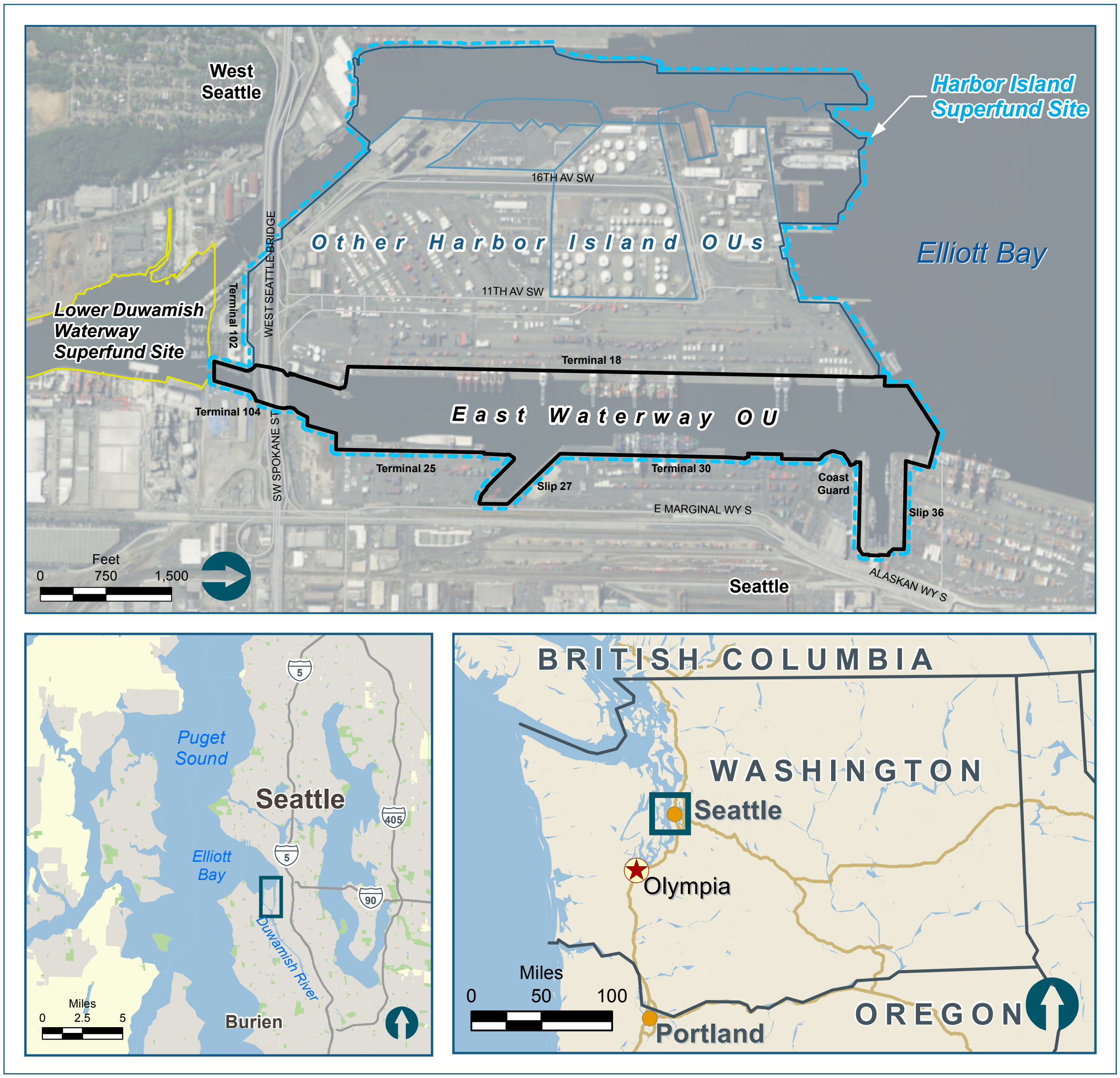
Contaminant Risks

Human health and ecological risks from contaminated sediments in the EW persist at levels that warrant action under federal and state law. Risks to people are highest from eating resident seafood that live in the waterway for most or all of their life.[2] Lower, but still significant, health risks to people come from sediment contact while clamming and netfishing. Animals that live in the sediment and some resident fish are also at risk.

1 Windward Environmental and Anchor QEA, 2014. Supplemental Remedial Investigation. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Final. January 2014.

2 Salmon caught within the EW do not accumulate significant contamination or pose health risks from EW sediments because salmon spend only a small portion of their lives in the EW, and thus are not considered resident fish.

Figure 1: East Waterway Study Area



Source Control

Most of the sediment contamination in the EW is from historical releases; however, continued efforts to reduce any ongoing sources of contaminants entering the EW is a priority, to avoid recontamination after cleanup. Discharges to the EW are heavily regulated under existing state and federal programs and regulations. Sediment from upstream sources can enter the EW from the Green/Duwamish River watershed, including the LDW Superfund site. The EWG members and other entities have performed investigations and cleanups of facilities, storm drains, and combined sewer overflows (CSOs) within the EW drainage basin, and future source control activities will further reduce contaminants entering the EW.

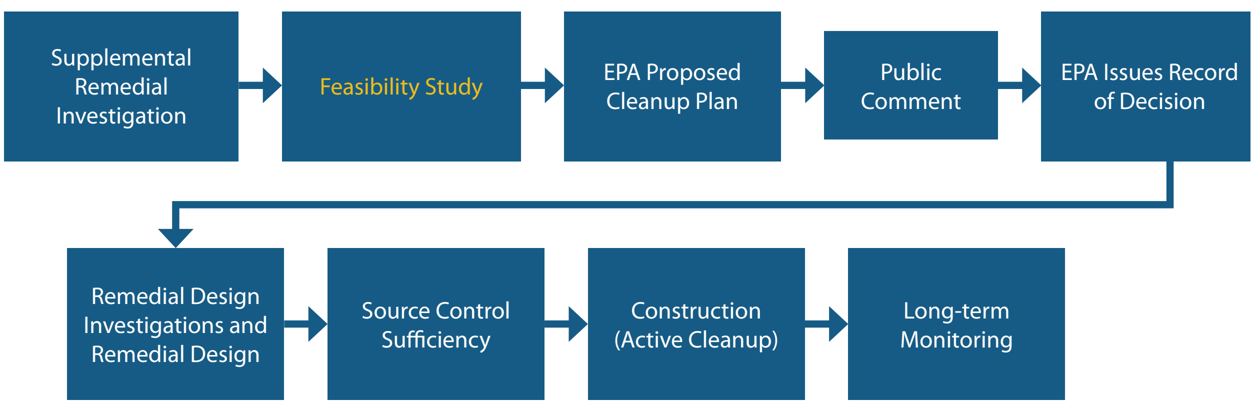
Cleanup Alternatives

The FS alternatives rely primarily on the removal (dredging) of contaminated sediment from the EW because the sediment bed elevation within most of the waterway is at the depth needed for navigation. Therefore, other cleanup options, such as capping that would raise the sediment bed elevation, are precluded in much of the EW. To varying lesser degrees, the alternatives also employ partial dredging and capping, capping (without dredging), in situ treatment, enhanced natural recovery (ENR), and monitored natural recovery (MNR). CERCLA criteria were used to develop and evaluate cleanup alternatives; this evaluation forms the basis for selecting a final cleanup plan in subsequent EPA decision documents.

CERCLA Process

Figure 2 presents the CERCLA process moving toward cleanup of the EW.

Figure 2: East Waterway Superfund Cleanup Process

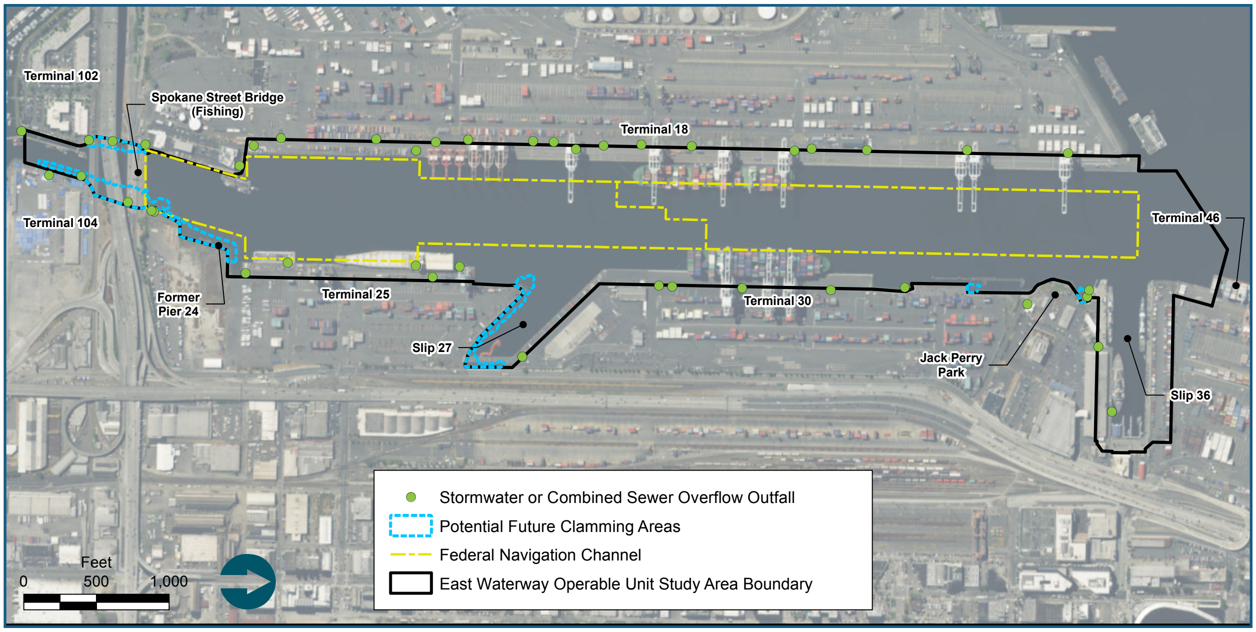


Key Definitions for the Executive Summary

- **Applicable or relevant and appropriate requirements (ARARs)** are defined as standards, criteria, or limitations under federal or state environmental or facility siting laws that are more stringent than the federal law. Remedial actions conducted under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) must achieve them or formally waive them. For example, the Washington Model Toxics Control Act (MTCA) is an ARAR under a CERCLA cleanup action.
- The **benthic community** is made up of organisms, such as marine worms and clams, that live in and on the sediments and are an integral part of the food chain in Puget Sound ecosystems.
- **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)** are the federal requirements that regulate the site investigations and cleanup of the EW OU Superfund site.
- **Construction Management Area (CMA)** refers to an area of the EW identified in the FS that represents similar structural conditions, or similar aquatic use, habitat, or water depth conditions for the purpose of determining the applicable cleanup technologies.
- **Enhanced natural recovery (ENR)** refers to the application of thin layers of clean granular material, typically sand, to reduce chemical exposure and accelerate natural recovery processes in a sediment area targeted for remediation. Essentially, ENR reduces the time to achieve cleanup objectives over what is possible by relying solely on natural sediment deposition.
- **In situ treatment** as a technology applied at this site refers to the application of an amendment to the material used in ENR or capping or mixed directly into surface sediments. Typically, the amendment is activated carbon or organoclays used to bind contaminants and make them unavailable for biological uptake by organisms.
- **Model Toxics Control Act (MTCA)** is the Washington State requirements for environmental cleanup sites and is an ARAR for the EW OU Superfund site.
- **Monitored natural recovery (MNR)** refers to the use of natural processes such as burial by incoming sediments to reduce sediment contaminant concentrations over time. It is used where conditions support natural recovery. A monitoring program is instituted to assess if, and at what rate, risks are being reduced and whether sufficient progress is being made toward achieving the RAOs, or alternatively, whether contingency actions are warranted.
- **Natural background** represents the concentrations of hazardous substances that are consistently present in an environment that has not been influenced by localized human activities.
- **Preliminary remediation goals (PRGs)** are specific desired contaminant endpoint concentrations or risk levels for each exposure pathway that are believed to provide adequate protection of human health and the environment, based on available site information.
- **Remedial action levels (RALs)** are contaminant-specific sediment concentrations that trigger the need for remediation (e.g., dredging, capping, in situ treatment, ENR, or MNR).
- **Remedial action objectives (RAOs)** describe what the proposed remedial action is expected to accomplish. They are narrative statements of the goals for protecting human health and the environment.
- **Risk drivers** are the COCs identified in the baseline (i.e., existing condition) risk assessments that present the principal risks to people or animals.
- **Sediment Management Standards (SMS)** include the Washington State requirements for sediment cleanup sites and are an ARAR for the EW OU Superfund site. The SMS rule has a two-tier decision framework (SQS/SCO and CSL) to protect the function and integrity of the benthic community and to protect humans and upper trophic levels from bioaccumulative effects.
- **Spatially-weighted average concentrations (SWACs)** are average concentrations in an area of interest (either site-wide or in potential clamming areas for the EW) calculated by interpolating concentration data over a specified area.

East Waterway Uses

Figure 3: East Waterway Features



The EW is one of the most active commercial waterways in the Pacific Northwest, supporting a variety of shipping and water-based industries (Figure 3). In addition, the EW serves ecological and recreational functions as a deep water estuary at the mouth of the Duwamish River. It also is an area used for a tribal commercial netfishery.

Commercial and Navigation Activities

The EW provides a critical connection for cargo and other materials moving between water and land, and current land use, zoning requirements, and land ownership are consistent with the characteristics of an active commercial waterway. Most vessel traffic consists of shipping companies that move container vessels and assorted tugboats into and out of the EW. A federally authorized navigation channel runs from the Spokane Street Bridge to the northern end of the EW. Berthing areas currently maintained to various depths are present inshore of the navigation channel along much of the waterway.

Habitat

The EW shoreline is highly developed, primarily composed of over-water piling-supported piers, riprap slopes, seawalls, and bulkheads for industrial and commercial use, with a limited number of small intertidal areas. Despite the commercial use and structures, the EW contains diverse aquatic and wildlife communities, including marine mammals and birds. The EW provides habitat important to various species, including two species that are listed as threatened under the Endangered Species Act, Puget Sound Chinook salmon and bull trout.

Other Uses

While the EW is used for various recreational activities such as boating and fishing, there is limited public access. There is one public park, Jack Perry Park, and a public fishing pier in the southern portion of the waterway. The EW is part of the Muckleshoot Tribe's and Suquamish Tribe's usual and accustomed area, which provides these tribes with treaty-protected uses including a commercial fishery for salmon as well as ceremonial and subsistence uses.

The EW is also the receiving waterbody for 39 public and private storm drains and three CSOs from adjacent urban areas.

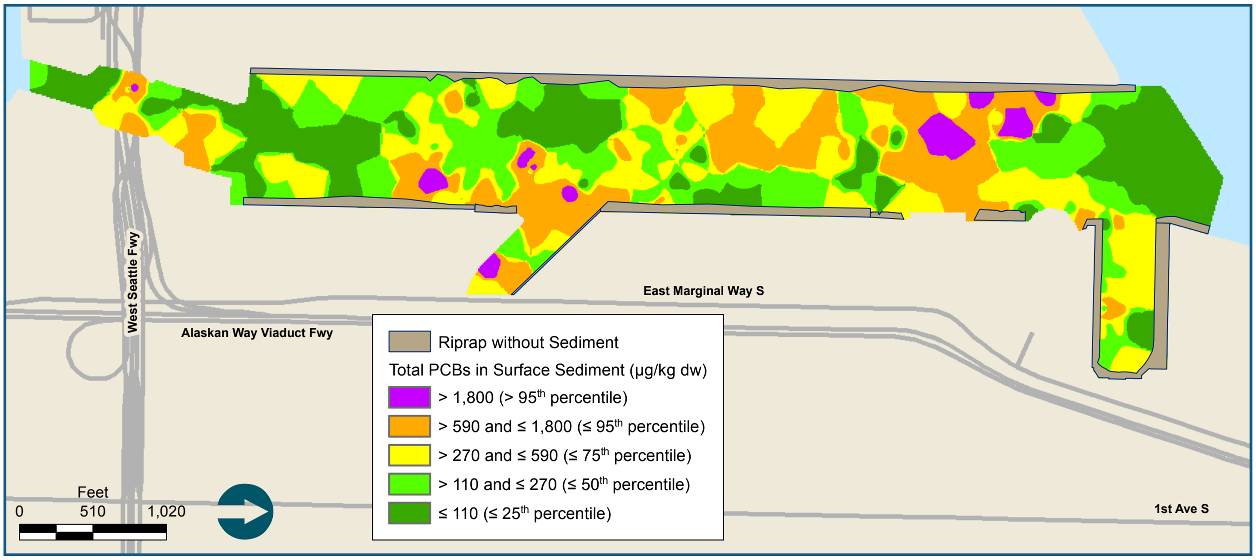
Nature and Extent of Contamination

For the SRI, scientists collected and analyzed information about the nature and extent of contamination and concluded with the following findings:

- PCBs, PAHs, dioxins/furans, phthalates, and metals were frequently detected in surface sediments.[3] Many other organic chemicals, including semivolatile organic compounds and pesticides, were less frequently or rarely detected. Contaminants are broadly distributed throughout the EW.
- Total PCBs are a key risk driver for the protection of human health and ecological health in the EW. Total PCBs surface sediment concentrations ranged from 6 to 8,400 micrograms per kilogram (µg/kg) on a dry weight (dw) basis, with a site-wide spatially-weighted average concentration (SWAC) of 460 µg/kg dw (Figure 4).
- A general depiction of the spatial extent and magnitude of contamination in surface sediment is provided by exceedance status of Washington State's Sediment Management Standards (SMS) marine benthic criteria. Figure 5 shows the spatial extent of contaminated sediment within the EW. Areas with sediment concentrations exceeding the cleanup screening level (CSL) have higher concentrations, areas with sediment exceeding sediment quality standard (SQS; but less than CSL) have moderate concentrations, and areas with sediment concentrations below the SQS have the lowest concentrations.
- The depth of sediment contamination exceeding the SQS averages approximately 5 feet.

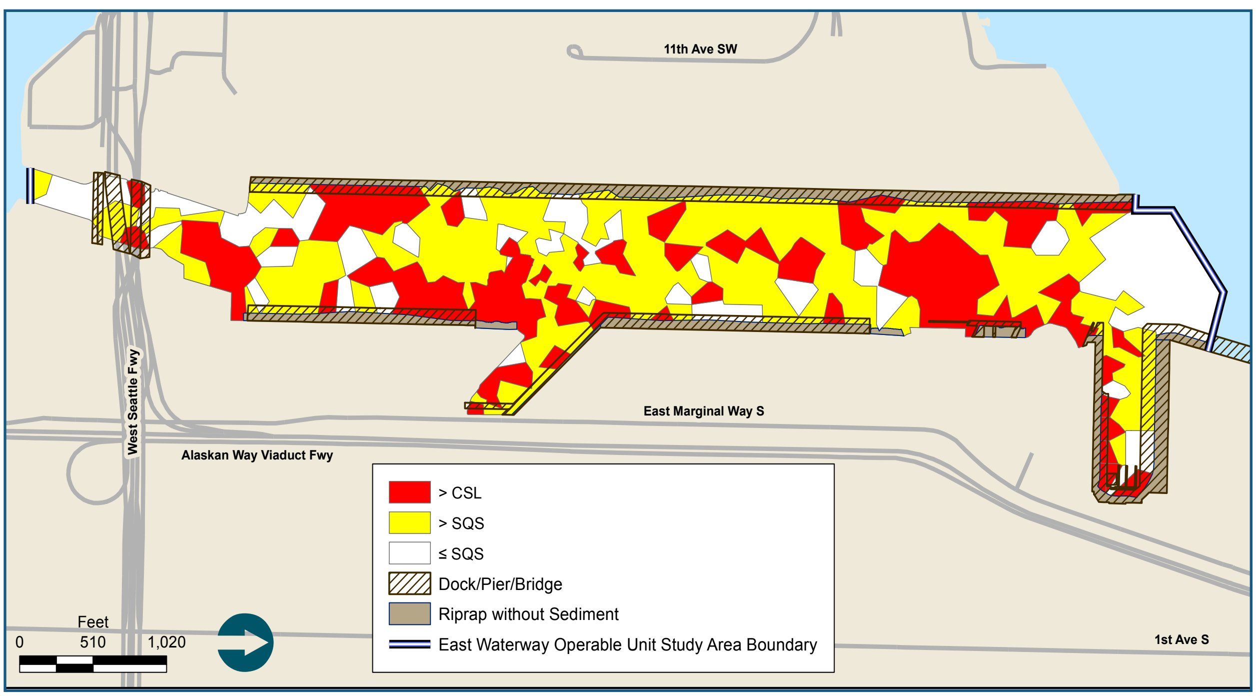
3 Surface sediment is defined as the upper 10 centimeters of sediment, also referred to as the biologically active zone, where the majority of the benthic community is generally found. Contaminants within the biologically active zone may pose risks to the benthic community and the animals that consume them.

Figure 4: Surface Sediment Total PCB Concentration



Notes: µg/kg dw – micrograms per kilogram on a dry weight basis | PCB – polychlorinated biphenyl

Figure 5: Surface Sediments Compared to Sediment Management Standards Marine Benthic Criteria



Notes: SQS – sediment quality standard | CSL – cleanup screening level

Fishing from the Spokane Street Bridge within the East Waterway. Photo: Anchor QEA

Risk Assessment

The baseline (i.e., existing condition) risk assessments conducted as part of the SRI estimated risks to people (human health) and ecological receptors (benthic community, fish, and wildlife) resulting from exposure to contaminants in the absence of any cleanup measures. The risk assessments found the risks in the EW to be high enough to warrant an evaluation of cleanup alternatives under CERCLA; these findings are summarized as follows:

Human Health Risks

- Contaminants contributing the most to human health risks are total PCBs, arsenic, cPAHs, and dioxins/furans. These are referred to as the human health risk drivers.
- The highest risks to people are associated with consumption of resident seafood, including fish, clams, and crab. The seafood consumption pathway is a significant exposure pathway and seafood can be obtained through tribal netfishing, clamming, crabbing, and hook-and-line fishing. The total excess cancer risk for all carcinogenic chemicals ranged from 4 in 10,000 (4×10^{-4}) to 1 in 1,000 (1×10^{-3}) for the reasonable maximum exposure (RME) seafood consumption scenarios. Total PCBs, dioxins/furans, and cPAHs were identified as risk drivers.

Reasonable Maximum Exposure Scenarios Developed for the EW

Seafood Consumption

- **Adult Tribal RME** = three meals per week (1/2 pound of seafood per meal) for 70 years
- **Child Tribal RME** = three meals per week (1/5 pound of seafood per meal) for 6 years
- **Adult Asian Pacific Islander RME** = one and a half meals per week (1/2 pound of seafood per meal) for 30 years

Sediment Direct Contact

- **Netfishing RME** = exposure for 119 days per year for 44 years
- **Tribal Clamming RME** = exposure for 120 days per year for 64 years

Photo: Benjamin Hollis (CC BY 2.0 License)

- The evaluation of non-cancer hazards (e.g., immunological or neurological effects) indicates the potential for adverse effects associated with resident seafood consumption. These non-cancer hazards have hazard quotients of up to 59 for the RME seafood consumption scenarios, with total PCBs and dioxins/furans identified as risk drivers.
- Excess cancer risks for direct sediment exposure RME scenarios for netfishing and tribal clamming were lower than those for seafood consumption RME scenarios, with total risk estimates ranging from 5 in 1,000,000 (5×10^{-6}) to 2 in 100,000 (2×10^{-5}). Arsenic was identified as a risk driver.

Benthic Risks

- The concentration of 29 contaminants in surface sediment in one or more locations exceeded the SMS marine standards, indicating at least the potential for minor adverse effects on the benthic community. Surface sediment also contains concentrations of tributyltin above the site-specific risk-based threshold concentrations (RBTCs). Approximately 38% of the EW is designated as having no adverse effects to the benthic community (all less than SQS), approximately 39% of the area has a potential for minor adverse effects to the benthic community (between SQS and CSL), and 23% of the area is expected to have at least minor adverse effects to the benthic community (greater than CSL). See Figure 5.

Ecological Risks

- Risks to crabs and fish were relatively low, with one exception. Risks associated with total PCBs were above the risk threshold for English sole and brown rockfish, and thus total PCBs were identified as an ecological risk driver. No contaminants were found to pose unacceptable risk to bird or mammal receptors.

Risk Assessment Terms

Cleanup Screening Levels (CSLs) in this Executive Summary represent the numeric marine benthic sediment chemical criteria for minor adverse effects to the benthic community. In the SMS, the CSL also represents the upper limit of the potential cleanup level considering multiple factors.

Excess Cancer Risk refers to the additional risk of developing cancer due to exposure to a toxic substance incurred over a defined exposure period, in this case lifetime exposure. Contaminant risk estimates that exceed the CERCLA threshold excess cancer risk level of 1 in 1,000,000 (1×10^{-6}) warrant further evaluation.

Hazard Quotient (HQ) is the ratio of the potential exposure to a substance and the level at which no adverse effects from that exposure are expected. Risk estimates that exceed the CERCLA threshold of HQ = 1 warrant further evaluation.

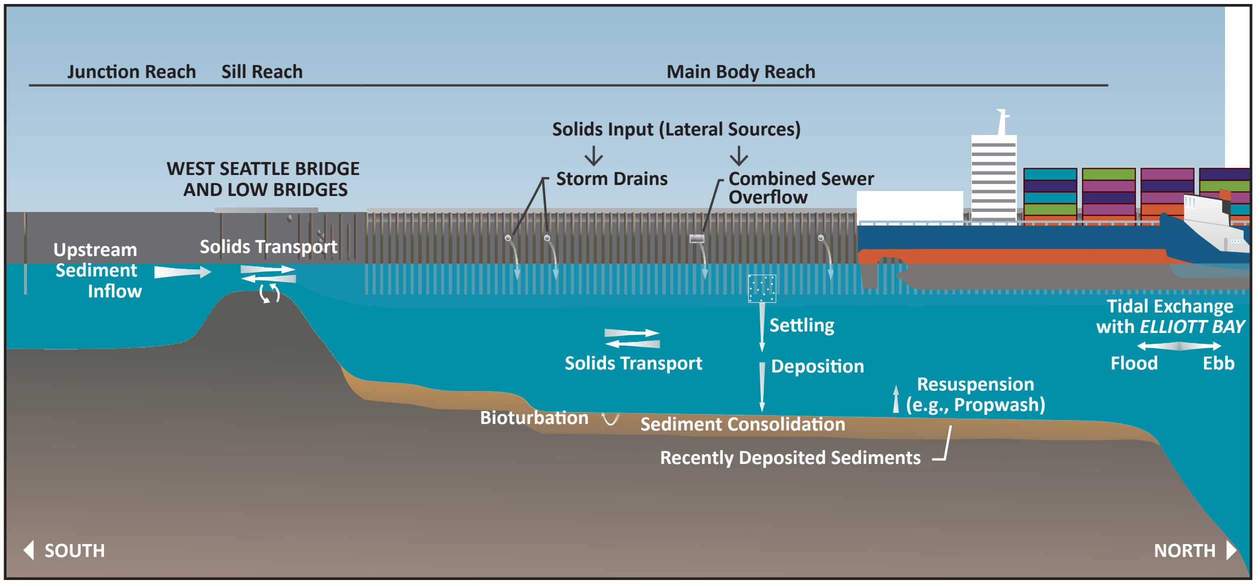
Reasonable Maximum Exposure (RME) is the maximum exposure reasonably expected to occur in a population.

Risk-based Threshold Concentration (RBTC) is the contaminant concentration in sediment that equates to a specific risk threshold. RBTCs are developed to meet specific cancer risk thresholds, HQs, or benthic criteria and are used in the development of preliminary remediation goals for the EW.

Sediment Quality Standards (SQSs) are the numeric marine sediment chemical criteria for Puget Sound, below which no adverse effects to the benthic community are expected; SQS also represents the "marine benthic sediment cleanup objective," which is the lower limit of the potential cleanup level considering multiple factors.

Physical and Chemical Modeling

Figure 6: Conceptual Site Model of Sediment Transport in the East Waterway



Hydrodynamic and sediment transport modeling and site-specific data collection were conducted to evaluate long-term sediment transport processes in the EW (the majority of contaminants are associated with sediments). The findings from these evaluations included the following:

- In most locations, sediments deposit and accumulate over time on the EW bottom. Data indicated that net sedimentation rates vary by location within the EW, from 0 to 4.2 centimeters per year.
- Newly deposited sediments are mixed with existing sediments through bioturbation and propeller wash (see Figure 6). Model-estimated vessel scour depths (i.e., the depth of sediment that could be impacted by vessel use during navigation and berthing) could range from 0.5 to 5 feet within the EW, depending on the location. The majority of the EW has potential for vessel scour of 2 feet or more from vessel use under normal to extreme operating conditions. Vessel scour is episodic and localized, with most of the scoured material re-depositing nearby.

Sedimentation in the EW

- 32,000 to 54,000 metric tons of sediment are estimated to enter the EW each year
- 40% to 75% are estimated to settle or accumulate in the EW
- Of the total sediment load entering the EW, it is estimated that:
  - » 99% originates from the Green/Duwamish River
  - » Less than1% originates from the upstream LDW Superfund site, including the LDW bed and LDW storm drains and CSOs
  - » 0.2% to 0.3% originates from EW storm drains and CSOs

- To evaluate changes in sediment contaminant concentrations over time, physical modeling results were combined with estimates of contaminant concentrations on solids that enter the EW. This analysis, conducted using hydrodynamic and particle tracking modeling, yielded the following results:
  - » 99% of solids settling in the EW originate upstream from the Green/Duwamish River watershed.
  - » Over the long term, contaminant concentrations in sediment in the EW trend toward net incoming solids concentrations, which are primarily governed by incoming sediment from the upstream Green/ Duwamish watershed.
  - » During cleanup construction activities (e.g., dredging and capping), and for 5 to 10 years following construction, contaminant concentrations are also affected by generated dredging residuals,[4] mixing with cleaner underlying sediment, and mixing of open-water and underpier sediments.
  - » Although less than 0.3% of new sediment is predicted to enter the EW from local storm drains and CSOs, these source sediments typically have higher contaminant concentrations than those associated with the upstream sediment inputs from the Green River watershed. Therefore, localized areas in the vicinity of some outfalls may have higher concentrations than surrounding areas.
  - » Modeling of environmental processes is inherently uncertain; therefore, the uncertainty in model predictions was examined with a sensitivity analysis. The sensitivity analysis shows that the predicted SWACs could vary by up to about +/-40% over the 40-year modeling period. In the long term, predicted SWACs are most sensitive to concentrations in Green River sediment inputs to the EW.

Photo: Port of Seattle

4 Generated dredging residuals are the thin layer of resuspended and redeposited sediment that result from the physical process of underwater sediment removal with large equipment.

Remedial Action Objectives and Preliminary Remediation Goals

Four remedial action objectives (RAOs) have been identified based on the risk assessments to describe what the cleanup actions aim to accomplish in the EW to address the identified risks. The RAOs are listed in the text box at right.

Preliminary remediation goals (PRGs) were developed for each RAO; they represent concentrations that are believed to provide adequate protection of human health and the environment. Depending on the RAO, PRGs for a given contaminant may be applied to individual locations (i.e., point-based), or applied as an average across the entire EW or over clamming areas. PRGs are not final cleanup levels. EPA will select cleanup levels in the Record of Decision (ROD).

The PRGs were developed for each risk driver COC, considering the following factors:

- ARARs, including Washington State SMS
- RBTCs based on the human health and ecological risk assessments
- Background concentrations if RBTCs are below background concentrations
- Analytical practical quantitation limits (PQLs) if RBTCs are below concentrations that can be quantified by chemical analysis

Both CERCLA and the SMS consider background concentrations when formulating PRGs and cleanup levels, recognizing that setting numerical cleanup goals at levels below background is impractical because such levels cannot be sustained over time. Both CERCLA and the SMS state that PRGs and cleanup levels cannot be set below natural background concentrations. Furthermore, both cleanup programs recognize that natural and human-made hazardous substance concentrations can occur at a site in excess of natural background concentrations, as a result of human activities that transport the contaminants to the site. The SMS defines the term "regional background" as concentrations that are consistently present in the environment in the vicinity of a site that are attributable to "diffuse nonpoint sources, such as atmospheric deposition or storm water, not attributable to a specific source or release." The Washington State Department of Ecology (Ecology) has not yet determined regional background for the EW; therefore, for the FS, PRGs are determined considering only RBTCs, natural background, and PQLs. The PRGs developed for this FS are presented in Table 1.

Remedial Action Objectives for the EW

RAO 1 (Human Health Seafood Consumption): Reduce risks associated with the consumption of contaminated resident EW fish and shellfish by adults and children with the highest potential exposure to protect human health.

RAO 2 (Human Health Direct Contact): Reduce risks from direct contact (skin contact and incidental ingestion) to contaminated sediments during netfishing and clamming to protect human health.

RAO 3 (Benthic Community): Reduce to protective levels risks to benthic invertebrates from exposure to contaminated sediments.

RAO 4 (Fish): Reduce to protective levels risks to crabs and fish from exposure to contaminated sediment, surface water, and prey.

Table 1: Summary of Preliminary Remediation Goals

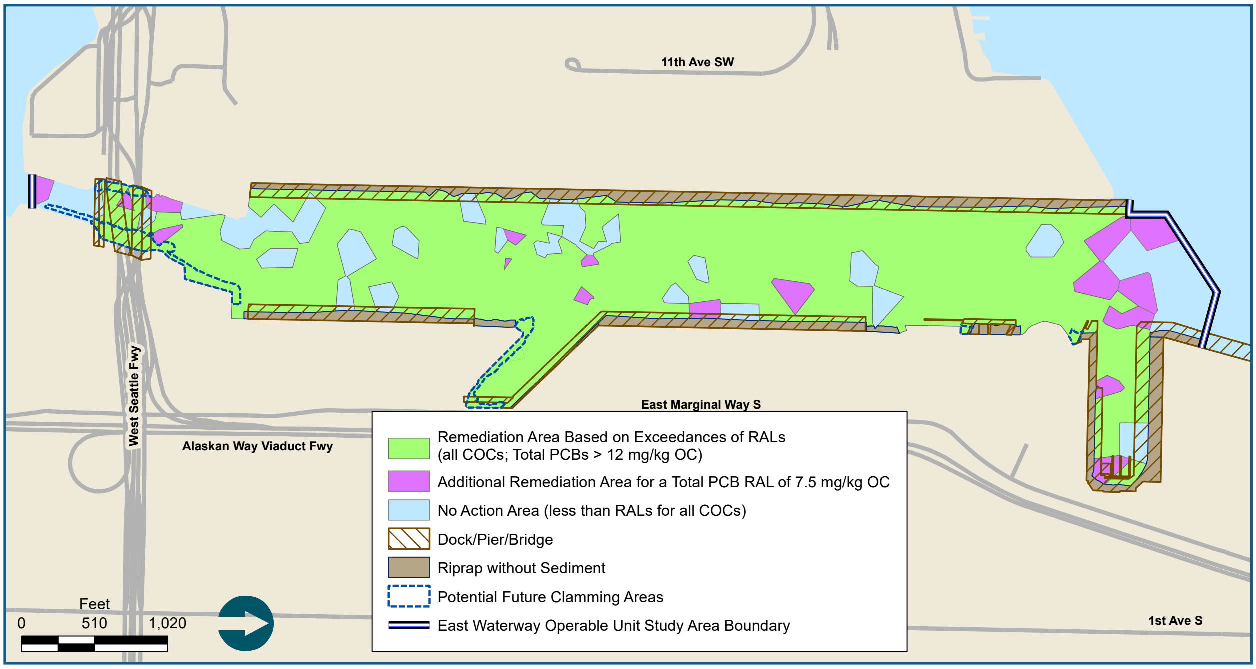
Risk Driver	PRG	Purpose	Basis	Spatial Scale
Total PCBs	2 µg/kg dw	Protection of Human Health for Seafood Consumption (RAO 1)	Natural background	Site-wide
	250, 370 µg/kg dw	Protection of Fish (RAO 4)	RBTC established based on brown rockfish (250) and English sole (370)	Site-wide
	12 mg/kg OC (SQS)	Protection of the Benthic Community (RAO 3)	RBTC	Point
Arsenic (mg/kg dw)	7	Protection of Human Health for Direct Contact (RAO 2)	Natural background	Site-wide (netfishing) and clamming areas (clamming)
	57 (SQS)	Protection of the Benthic Community (RAO 3)	RBTC	Point
Dioxins/furans (ng TEQ/kg dw)	2	Protection of Human Health for Seafood Consumption (RAO 1)	Natural background	Site-wide
TBT (mg/kg OC)	7.5	Protection of the Benthic Community (RAO 3)	RBTC	Point
Other benthic risk drivers	SQS	Protection of the Benthic Community (RAO 3)	RBTC	Point

Notes:

µg – microgram
dw – dry weight
mg – milligram
kg – kilogram
ng – nanogram
OC – organic carbon
PCBs – polychlorinated biphenyls
PRG – preliminary remediation goal
RAO – remedial action objective
RBTC – risk-based threshold concentration
SQS – sediment quality standard
TBT – tributyltin
TEQ – toxic equivalent

Remedial Action Levels and Remediation Areas

Figure 7: Remediation Areas



Notes:
COC – contaminant of concern
mg/kg – milligrams per kilogram
OC – organic carbon
PCBs – polychlorinated biphenyl
RAL – remedial action level

Remedial action levels (RALs) are contaminant-specific sediment concentrations that trigger the need for cleanup action (i.e., dredging, capping, in situ treatment, ENR, or MNR). The RALs are designed to meet the RAOs described in the previous section.

RALs were developed for four human health risk driver COCs and eight key benthic risk driver COCs (Table 2). Remediation of these risk drivers will also address the remaining risk driver COCs because they are less widely distributed, and where they are elevated, they are located in areas needing remediation for other chemicals. For total PCBs, two RALs (12 mg/kg OC and 7.5 mg/kg OC[5]) were developed for the purpose of comparing remedial alternatives. For other key risk driver COCs, a single set of RALs was used for all alternatives.

The existing surface sediment and shallow subsurface sediment chemistry data were compared to RALs to identify the areas requiring remediation for the FS alternatives.

Shallow subsurface sediment was included in developing remediation footprint in areas where vessels have the potential to disturb subsurface sediment due to propeller action. All of the alternatives remediate the majority of the waterway, with 121 of 157 acres remediated for the RALs that include 12 mg/kg OC for total PCBs, and 132 of 157 acres remediated for the RALs that include 7.5 mg/kg OC for total PCBs (Figure 7). Areas and volumes requiring remediation will be refined through additional sampling during remedial design.

5 An organic-carbon normalized RAL was selected for total PCBs to be consistent with the marine benthic standard and to acknowledge the role of organic carbon in PCB bioavailability.

Table 2: Remedial Action Levels and Objectives Achieved

Risk Driver	RAL	RAO 1 (Human Health Seafood Consumption)	RAO 2 (Human Health Direct Contact)	RAO 3 (Protection of Benthic Invertebrates)	RAO 4 (Ecological-Fish)
Total PCBs (mg/kg OC)	12 or 7.5 (site-wide)	Not expected to achieve the natural background-based PRGs. Both RALs result in significant risk reduction.		Achieves PRG of 12 mg/kg OC	Achieves PRGs of 250 and 370 µg/kg dw
Dioxins/furans (ng TEQ/kg dw)	25 (site-wide)				
Arsenic (mg/kg dw)	57 (site-wide)		Achieves PRG of 7 mg/kg dw both site-wide and in clamming areas	Achieves PRG of 57 mg/kg dw	
TBT (mg/kg OC)	7.5 (site-wide)			Achieves PRG of 7.5 µg/kg OC	
Additional SMS Benthic Key Risk Driver COCs: 1,4-dichlorobenzene, butylbenzylphthalate, acenaphthene, fluoranthene, fluorene, mercury, phenanthrene	SQS (benthic SCO; site-wide)			RALs collectively achieve the PRGs for all 29 benthic risk-drivers	

Notes:

a. RALs are developed and presented in Section 6.

b. PCB RAL of 12 mg/kg OC was selected for consistency with the marine standard (SQS), and 7.5 mg/kg OC was considered to assess the effect of a lower RAL on site-wide total PCB concentrations.

Predicted to achieve the PRG or risk threshold

Not applicable

µg – micrograms
COC – contaminant of concern
dw – dry weight
kg – kilograms
mg – milligrams
OC – organic carbon
ng – nanograms
PCB – polychlorinated biphenyl
PRG – preliminary remediation goal
RAL – remedial action level
RAO – remedial action objective
SCO – sediment cleanup objective
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
TBT – tributyltin
TEQ – toxic equivalent

Evaluation and Screening of Remedial Technologies

A number of potential technologies were evaluated for remediating contaminated sediments in the EW. Of these, several technologies were retained to develop the remedial alternatives:

- **Removal** (e.g., dredging) of contaminated sediments. Dredged sediment would be disposed of in an off-site facility (e.g., in a permitted landfill). Based on site conditions, mechanical dredging would be used in open-water areas, and diver-assisted hydraulic dredging would be required in underpier areas.
- **Capping** (i.e., containment) of contaminated sediments, using engineered layers of sand, gravel, or rock. In the FS, capping is used in conjunction with partial removal to maintain appropriate water depths for navigation (partial removal and capping). Habitat quality is also a consideration in engineered cap design.
- **ENR** that uses a thin layer placement of material (e.g., sand) to accelerate natural recovery processes. In the FS, ENR in the navigation channel is referred to as ENR-nav, and ENR used in the sill reach (Figure 6) is referred to as ENR-sill.
- **In situ treatment** that adds activated carbon or other sequestering agents to sediments to reduce the bioavailability and toxicity of contaminants. In the FS, in situ treatment is used to remediate underpier sediments only.
- **MNR** that reduces surface sediment concentrations, by the natural burial and mixing of contaminated sediments with cleaner sediments over time. In the FS, MNR is used to remediate difficult to access sediments only.

These technologies have been used in the Puget Sound region and nationally at other contaminated sediment sites. Other similar technologies may be considered during remedial design.

The retained remedial technologies can be applied at different locations within the EW, depending on the site use (e.g., navigation and maintenance dredging), equipment access considerations (e.g., under piers and bridges), structural considerations (e.g., pile-supported piers, bridges, and riprap slopes), physical conditions (e.g., propwash depths and sedimentation rates), and chemical conditions (e.g., depth of contamination, magnitude of RAL exceedances, and contribution to site risk). Based on these factors, the EW was divided into construction management areas (CMAs) that represent areas with similar engineering considerations and conditions (Figure 8), and remedial technologies were retained or eliminated from consideration within each CMA.

Monitoring of sediments, biota, and water will provide the data needed to understand conditions before, during, and after remediation of the EW by any combination of the remedial technologies. Information gathered during monitoring will be used to assess the effectiveness of each of the technologies and inform the need for any adaptive management decisions. To varying degrees, institutional controls will be needed to supplement the remedial technologies (e.g., advisories to limit consumption of resident seafood from the EW or restrictions on activities such as maintenance dredging or anchoring in areas that have been capped).

Summary of Retained Remediation Technologies

Open-water Areas

- Removal (mechanical dredging)
- Partial removal and capping
- ENR

Underpier Areas

- MNR
- In situ treatment
- Diver-assisted hydraulic dredging

Remedial Alternatives

In coordination with EPA, a total of 16 remedial alternatives were initially developed by varying three components: 1) the remedial technology assignments in the open-water areas that are generally accessible to barge-mounted construction equipment; 2) the remedial technology assignments in areas with limited access to construction equipment, such as under piers; and 3) the RALs that result in variation of the remediation footprint. In consultation with EPA, alternatives were screened down to ten representative alternatives for detailed analysis. Table 3 shows the ten retained alternatives and the three components of the alternatives. The No Action Alternative is included for comparison, and the other alternatives are referred to collectively as the action alternatives.

All of the action alternatives rely primarily on removal (i.e., dredging) of contaminated sediment from the waterway because the sediment bed elevation within most of the waterway is at the depth needed for navigation. Therefore, other cleanup options, such as capping that would raise the sediment bed elevation, are precluded in much of the EW.

Remediation of difficult-to-access sediments (e.g., under piers) presents major technical challenges for cleanup of the EW; therefore, a range of technologies are evaluated. The range of technologies presented in the alternatives includes MNR, ENR, placement of in situ treatment material, and diver-assisted hydraulic dredging. Technologies were assigned to CMAs, as shown in Figure 8.

The alternatives are summarized in Table 3. The total areas, volumes, construction timeframes, and costs are shown for each alternative in Table 4 and Figure 9. The costs to implement the action alternatives range from $256 to $411 million dollars, and the estimated time to complete construction on active cleanup components ranges from 9 to 13 years.

- The **No Action Alternative** provides a basis for comparison for the other remedial alternatives and is required by CERCLA. This alternative includes no action other than long-term monitoring and provides no institutional controls beyond the existing Washington State Department of Health seafood consumption advisory.

Figure 8: Construction Management Areas Used to Develop the Alternatives

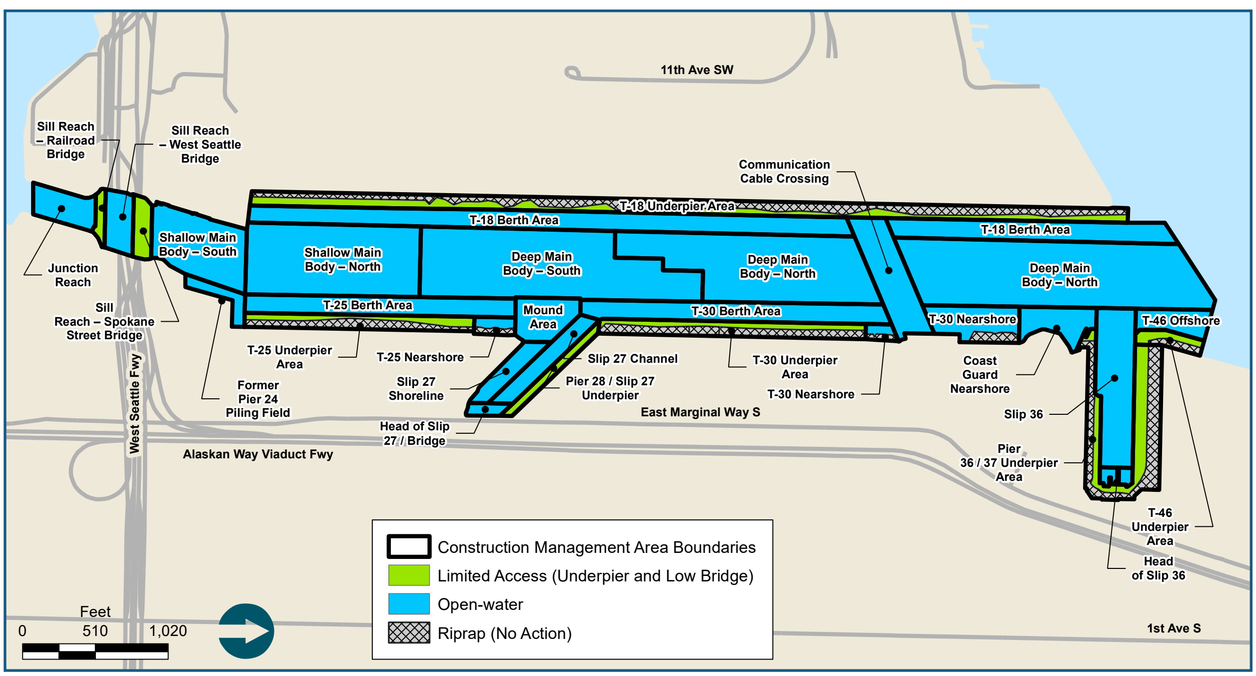


Table 3: Retained Alternatives and Alternative Key

Action Alternatives	Technologies for Open-water Areas	Technologies for Restricted Access Areas (Underpier and Low Bridges)	PCBs RAL All Areas
No Action			
1A(12)	1. Removal with capping and ENR where applicable	A MNR	(12) 12 mg/kg OC
1B(12)		B In situ treatment	
1C+(12)		C+ Diver-assisted hydraulic dredging followed by in situ treatment for PCBs or mercury > CSL; in situ treatment elsewhere	
2B(12)	2. Removal with capping where applicable	B In situ treatment	
2C+(12)		C+ Diver-assisted hydraulic dredging followed by in situ treatment for PCBs or mercury > CSL; in situ treatment elsewhere	
3B(12)	3. Maximum removal to the extent practicable	B In situ treatment	
3C+(12)		C+ Diver-assisted hydraulic dredging followed by in situ treatment for PCBs or mercury > CSL; in situ treatment elsewhere	
2C+(7.5)	2. Removal with capping where applicable		(7.5) 7.5 mg/kg OC
3E(7.5)	3. Maximum removal to the extent practicable	E Diver-assisted hydraulic dredging followed by in situ treatment	

Notes:

CSL – cleanup screening level
ENR – enhanced natural recovery
mg/kg – milligrams per kilogram
MNR – monitored natural recovery
OC – organic carbon
PCB – polychlorinated biphenyl
RAL – remedial action level

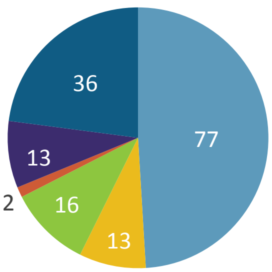
- **Alternative 1A(12)** employs open-water option 1 (removal with capping and ENR where applicable), restricted access option A (MNR in the underpier areas) and RALs that include 12 mg/kg OC for total PCBs. In sum, Alternative 1A(12) remediates 121 acres, primarily through removal (77 acres; 810,000 cy of sediment removed), followed by ENR (including partial removal and ENR-nav, ENR-nav, and ENR-sill; 18 acres), partial removal and capping (13 acres), and MNR (13 acres).
- **Alternative 1B(12)** employs open-water option 1 (removal with capping and ENR where applicable), restricted access option B (in situ treatment in the underpier areas) and RALs that include 12 mg/kg OC for total PCBs. In sum, Alternative 1B(12) remediates 121 acres of the EW, primarily through removal (77 acres; 810,000 cy of sediment removed), followed by ENR (including partial removal and ENR-nav, ENR-nav, and ENR-sill; 19 acres), partial removal and capping (13 acres), and in situ treatment (12 acres).

All Action Alternatives Rely on Removal of Contaminated Sediment

- Between 80% to 99% of the remediation area would undergo removal or partial removal
- 810,000 to 1,080,000 cy of removal

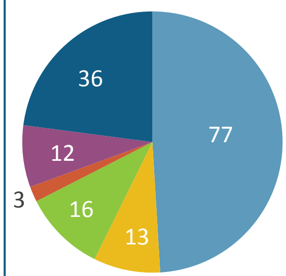
Figure 9: Comparison of Action Alternatives

Alternative 1A(12)



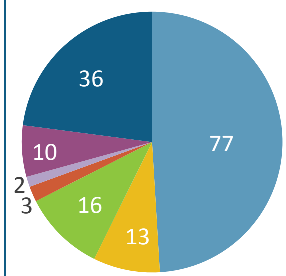
Construction Time (yr)	9
Removal Volume (cy)	810,000
Placement Volume (cy)	290,000
Costs ($)	$256M

Alternative 1B(12)



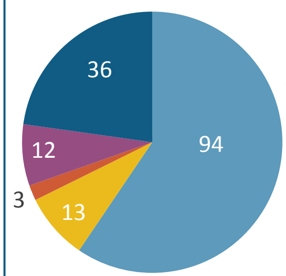
Construction Time (yr)	9
Removal Volume (cy)	810,000
Placement Volume (cy)	290,000
Costs ($)	$264M

Alternative 1C+(12)



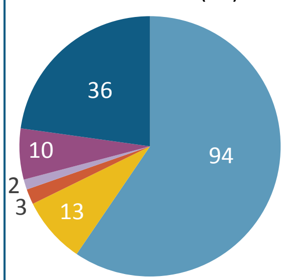
Construction Time (yr)	9
Removal Volume (cy)	820,000
Placement Volume (cy)	290,000
Costs ($)	$277M

Alternative 2B(12)



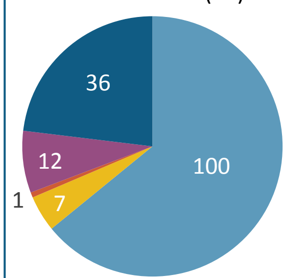
Construction Time (yr)	10
Removal Volume (cy)	900,000
Placement Volume (cy)	280,000
Costs ($)	$284M

Alternative 2C+(12)



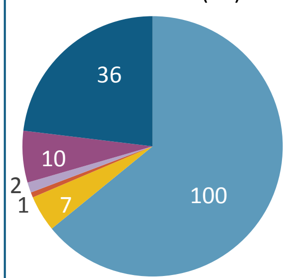
Construction Time (yr)	10
Removal Volume (cy)	910,000
Placement Volume (cy)	280,000
Costs ($)	$297M

Alternative 3B(12)



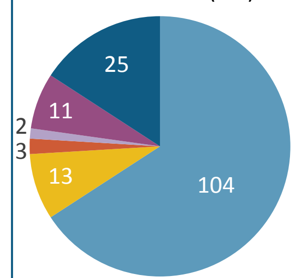
Construction Time (yr)	10
Removal Volume (cy)	960,000
Placement Volume (cy)	270,000
Costs ($)	$298M

Alternative 3C+(12)



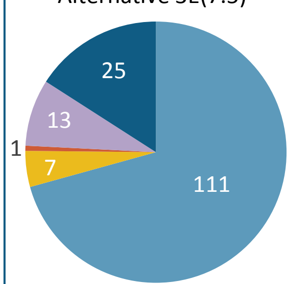
Construction Time (yr)	10
Removal Volume (cy)	960,000
Placement Volume (cy)	270,000
Costs ($)	$310M

Alternative 2C+(7.5)



Construction Time (yr)	11
Removal Volume (cy)	1,010,000
Placement Volume (cy)	290,000
Costs ($)	$326M

Alternative 3E(7.5)



Construction Time (yr)	13
Removal Volume (cy)	1,080,000
Placement Volume (cy)	270,000
Costs ($)	$411M

Legend:

- Removal – Open Water
- Partial Removal and Capping
- Partial Removal and ENR-nav or ENR-nav
- ENR-sill
- MNR
- In Situ Treatment
- Hydraulic Dredging Followed by In Situ Treatment
- No Action Area

Notes:

a. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation.

b. Costs are net present value and 2016 dollars.

cy – cubic yard

ENR-nav – enhanced natural recovery applied in the navigation channel

ENR-sill – enhanced natural recovery applied in the Sill Reach

MNR – monitored natural recovery

yr – year

- **Alternative 1C+(12)** employs open-water option 1 (removal with capping and ENR where applicable), restricted access ion C+ (diver-assisted hydraulic dredging followed by in situ treatment for total PCBs or mercury > CSL; in situ treatment elsewhere exceeding RALs in the underpier areas), and RALs that include 12 mg/kg OC for total PCBs. In sum, Alternative 1C+(12) remediates 121 acres of the EW, primarily through removal (77 acres; 820,000 cy of sediment removed), followed by ENR (including partial removal and ENR-nav, ENR-nav, and ENR-sill; 19 acres), partial removal and capping (13 acres), in situ treatment (10 acres), and diver-assisted hydraulic dredging followed by in situ treatment (2 acres).
- **Alternative 2B(12)** employs open-water option 2 (removal with capping where applicable), restricted access option B (in situ treatment in the underpier areas) and RALs that include 12 mg/kg OC for total PCBs. In sum, Alternative 2B(12) remediates 121 acres of the EW, primarily through removal (94 acres; 900,000 cy of sediment removed), followed by partial removal and capping (13 acres), in situ treatment (12 acres), and ENR-sill (3 acres).
- **Alternative 2C+(12)** employs open-water option 2 (removal with capping where applicable), restricted access option C+ (diver-assisted hydraulic dredging followed by in situ treatment for total PCBs or mercury > CSL; in situ treatment elsewhere exceeding RALs in the underpier areas), and RALs that include 12 mg/kg OC for total PCBs. In sum, Alternative 2C+(12) remediates 121 acres of the EW, primarily through removal (94 acres; 910,000 cy of sediment removed), followed by partial removal and capping (13 acres), in situ treatment (10 acres), ENR-sill (3 acres), and diver-assisted hydraulic dredging followed by in situ treatment (2 acres).
- **Alternative 3B(12)** employs open-water option 3 (maximum removal area with less capping, to the extent practicable), restricted access option B (in situ treatment in the underpier areas) and RALs that include 12 mg/kg OC for total PCBs. In sum, Alternative 3B(12) remediates 121 acres of the EW, primarily through removal (100 acres; 960,000 cy of sediment removed), followed by in situ treatment (12 acres), partial removal and capping (7 acres), and ENR-sill (1 acre).
- **Alternative 3C+(12)** employs open-water option 3 (maximum removal area with less capping, to the extent practicable), restricted access option C+ (diver-assisted hydraulic dredging followed by in situ treatment for total PCBs or mercury > CSL; in situ treatment elsewhere exceeding RALs in the underpier areas), and RALs that include 12 mg/kg OC for total PCBs. In sum, Alternative 3C+(12) remediates 121 acres of the EW, primarily through removal (100 acres; 960,000 cy of sediment removed), followed by in situ treatment (10 acres), partial removal and capping (7 acres), diver-assisted hydraulic dredging followed by in situ treatment (2 acres), and ENR-sill (1 acre).
- **Alternative 2C+(7.5)** employs open-water option 2 (removal with capping where applicable), restricted access option C+ (diver-assisted hydraulic dredging followed by in situ treatment for total PCBs or mercury > CSL; in situ treatment elsewhere exceeding RALs in the underpier areas), and RALs that include 7.5 mg/kg OC for total PCBs. In sum, Alternative 2C+(7.5) remediates 132 acres of the EW, primarily through removal (104 acres; 1,010,000 cy of sediment removed), followed by partial removal and capping (13 acres), in situ treatment (11 acres), ENR-sill (3 acres), and diver-assisted hydraulic dredging followed by in situ treatment (2 acres).
- **Alternative 3E(7.5)** employs open-water option 3 (maximum removal area with less capping, to the extent practicable), restricted access option E (diver-assisted hydraulic dredging followed by in situ treatment in the underpier areas), and RALs that include 7.5 mg/kg OC for total PCBs. In sum, Alternative 3E(7.5) remediates 132 acres of the EW, primarily through removal (111 acres; 1,080,000 cy of sediment removed), followed by partial removal and capping (7 acres), ENR-sill (1 acre), and diver-assisted hydraulic dredging followed by in situ treatment (13 acres).

Detailed Evaluation and Comparative Analysis of Remedial Alternatives

The retained remedial alternatives were evaluated using seven of the nine CERCLA criteria, which include two threshold criteria and five balancing criteria. The two threshold criteria, which must be met before the others can be considered, are:

- Overall protection of human health and the environment
- Compliance with ARARs of federal and state environmental laws and regulations

The five balancing criteria are:

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost

The two modifying criteria, state/tribal and community acceptance, were not evaluated at this time. EPA will evaluate state, tribal, and community acceptance of the selected remedial action in the ROD following the public comment period on EPA's Proposed Plan.

Figure 9 and Table 4 summarize the comparison of the alternatives. The No Action Alternative does not provide adequate protection of human health and the environment, engineering controls, or institutional controls and is not expected to meet all RAOs; thus, it does not meet threshold criteria and is not discussed further in the Executive Summary. The key points of this comparative analysis are summarized in the following pages.

Overall Protection of Human Health and the Environment

Assessment of overall protection of human health and the environment primarily draws on evaluation of long-term effectiveness and short-term effectiveness. All of the action alternatives meet the threshold requirement of overall protection of human health and the environment by reducing risks to human health and the environment for each of the RAOs during and following construction of active cleanup. Although PCB concentrations in sediment can be greatly reduced, not all PRGs because of background concentrations are predicted to be achieved, and institutional controls, specifically fish consumption advisories, will be needed to limit exposures. Long-term effectiveness and short-term effectiveness are

Photo: Port of Seattle

Table 4: Summary of Alternatives Comparison

	Alternative									
	No Action	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Threshold Criteria										
Overall Protection of Human Health and the Environment										
Magnitude and Type of Residual Risk										
RAO 1 (Individual Excess Cancer Risk 40 Years After Construction; Total for PCBs and Dioxins/Furans)										
Adult Tribal RME	5×10^{-4}	3×10^{-4}	2×10^{-4}							
Child Tribal RME	9×10^{-5}	5×10^{-5}	4×10^{-5}							
Adult API RME	2×10^{-4}	1×10^{-4}	9×10^{-5}							
RAO 2 (Total Excess Cancer Risk 40 Years After Construction; Arsenic)										
Site-wide Netfishing or Clamming	$<1 \times 10^{-5}$									
RAO 3 (40 Years After Construction; 29 COCs)										
Point Locations Predicted to Meet Benthic PRGs	Not expected to achieve	99%	100%							
RAO 4 (HQ 40 Years After Construction; Total PCBs)										
English Sole and Brown Rockfish	>1 using the lowest toxicity threshold	>1[a]	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
Compliance with ARARs	**No**	**Yes**; however, one or more ARAR waivers may be required.								
Active Threshold Criteria?	**No**	**Yes**								
Balancing Criteria										
Long-term Effectiveness and Permanence										
Long-term Risk Outcomes	Does not achieve all	See the risk outcomes for Magnitude and Type of Residual Risk above. The action alternatives achieve similar risk outcomes, with Alternative 1A(12) having slightly higher risks.								
Technology Areas (acres; of 157 acres in the EW)										
Most Permanent: Removal	No controls assumed	77	77	79	94	94	100	100	104	111
Highly Permanent: Partial Dredging and Capping		13	13	13	13	13	7	7	13	7
Moderately permanent: in situ treatment		0	12	12	12	12	12	12	13	13
Less Permanent: ENR-nav, ENR-sill, and MNR		31	19	19	3	3	1	1	3	1
Ranking	★	★★★	★★★★	★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★

			Alternative								
		No Action	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Reduction of Toxicity, Mobility, or Volume Through Treatment											
	Ranking	★	★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
Short-term Effectiveness											
Impacts During Construction	Construction timeframe (years)	NA	9	9	9	10	10	10	10	11	13
	Diver-assisted Dredging Timeframe (years)	NA	NA	NA	2	NA	2	NA	2	2	12
	Total Removal Volume / Consumed Landfill Capacity (cy)	NA	810,000 / 970,000	810,000 / 970,000	820,000 / 980,000	900,000 / 1,080,000	910,000 / 1,090,000	960,000 / 1,150,000	960,000 / 1,150,000	1,010,000 / 1,210,000	1,080,000 / 1,300,000
	Air Quality Impacts (CO_2/PM_{10} Emissions; metric tons)	NA	16,000 / 5.4	16,000 / 5.6	16,000 / 5.9	17,000 / 6.1	18,000 / 6.3	18,000 /6.4	18,000 / 6.6	19,000 / 7.0	23,000 / 8.3
	Carbon Footprint (acre-years)	NA	3,800	3,800	3,800	4,000	4,300	4,300	4,300	4,500	5,400
Time to Achieve RAOs (Years from Start of Construction)[b]	Human Health – Seafood Consumption (RAO 1 – Natural Background PRGs)	Does not achieve	Not predicted to achieve.								
	Human Health – Seafood Consumption (RAO 1 – Risk Ranges)[c]	Does not achieve	34	9	9	10	10	10	10	11	13
	Human Health – Direct Contact (RAO 2)	Does not achieve	9	9	9	10	10	10	10	11	13
	Ecological Health – Benthic Organisms (RAO 3)	Not expected to achieve	39	9	9	10	10	10	10	11	13
	Ecological Health – Fish (RAO 4)	25	9	9	9	10	10	10	10	11	13
	Ranking	★	★★	★★★★★	★★★★	★★★★	★★★	★★★★	★★★	★★	★
Implementability											
	Ranking	★★★★★	★★★★	★★★	★★	★★★	★★	★★★	★★	★★	★

	Alternative									
	No Action	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Costs										
Total Costs	$950K	$256MM	$264MM	$277MM	$284MM	$297MM	$298MM	$310MM	$326MM	$411MM
Ranking	★★★★★	★★★★	★★★★	★★★	★★★	★★★	★★★	★★	★★	★

Notes:

a. Alternative 1A(12) has an HQ ≤1, except for brown rockfish lowest toxicity threshold, which is >1 due to water exposure.

b. The time to achieve RAOs is at the end of construction for many alternatives and metrics. In these instances, the time to achieve could be reduced by approximately 2 years (for all action alternatives) if a longer annual construction window is feasible in the EW.

c. Time to achieve RAO 1 is based on risk-reduction milestones. Long-term modeling results predict that none of the alternatives will achieve the RAO 1 natural background-based PRGs for total PCBs and dioxins/furans.

API – Asian Pacific Islander
ARAR – applicable and relevant or appropriate requirements
CO_2 – carbon dioxide
COC – contaminant of concern
cy – cubic yards
ENR-nav – enhanced natural recovery applied in the navigation channel or berthing areas
ENR-sill – enhanced natural recovery applied in the sill reach
EW – East Waterway
HQ – hazard quotient
K – thousand
MM – million
MNR – monitored natural recovery
NA – not applicable
PM_{10} – particulate matter less than 10 microns in diameter
PRG – preliminary remediation goal
RAO – remedial action objective
RME – reasonable maximum exposure

also balancing criteria; the comparative rankings of the alternatives for these criteria are discussed in the following sections.

Compliance with ARARs

Two key ARARs for the EW cleanup are the Washington State SMS (Washington Administrative Code 173-204), which are promulgated under MTCA to define how sediment sites meet MTCA, and federal recommended and state surface water quality criteria and standards.

The SMS provide rules for developing cleanup levels considering multiple exposure pathways, background concentrations, and PQLs. The PRGs were developed to be consistent with the rules for cleanup level determination in the SMS, but without considering regional background, as it has not been defined for this area (see Appendix A for additional details[6]). All of the action alternatives achieve SMS standards for protectiveness of human health for direct contact (RAO 2), protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs or target risk levels for these RAOs, either immediately following construction of active cleanup or following construction plus a period of natural recovery. For protection of human health for seafood consumption (RAO 1), each of the action alternatives achieves similar reductions in risk.

As shown in Table 4, some natural-background-based PRGs are not predicted to be achieved by any alternative (e.g., total PCBs for RAO 1), primarily because of the large influence of incoming Green River sediment (which exceeds EPA-derived natural background concentrations based

6 SMS allows the upward adjustment of cleanup levels to "regional background." Regional background has not been determined for the EW and, therefore, has not been considered in this FS.

on Puget Sound data).[7] However, following source control and remediation efforts, all of the action alternatives will comply with MTCA/SMS in the long term, consistent with the substantive requirements of SMS. Following remediation and long-term monitoring, a final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs such that a TI waiver would be warranted for those ARARs.

All of the alternatives must comply substantively with relevant and appropriate state water quality standards and any more stringent federal recommended surface water quality criteria upon completion of the remedial action, except to the extent that they may be formally waived by EPA. While significant water quality improvements are anticipated from sediment remediation and source control, current upstream Green River and downstream Elliott Bay water concentrations are often above federal recommended water quality criteria for some chemicals, and therefore it is not technically practicable for any alternative to meet all human health federal recommended or state ambient water quality criteria or standards based on human consumption of bioaccumulative contaminants (e.g., total PCBs and arsenic). Like MTCA/SMS requirements, if long-term monitoring data and trends indicate that water quality ARARs cannot be met, EPA will determine whether further remedial action could practicably achieve the ARAR. If EPA concludes that an ARAR cannot be practicably achieved, EPA may waive the ARAR on the basis of technical impracticability in a future decision document (ROD Amendment or ESD).

Long-term Effectiveness and Permanence

This balancing criterion compares the relative magnitude and type of residual risk (i.e., the risk that remains following cleanup) that would remain in the EW after remediation under each alternative. In addition, it assesses the extent and effectiveness of the controls that may be required to manage the residual risks from contamination remaining at the site after remediation.

The magnitude of residual risk in surface sediment was assessed by comparing the predicted outcomes of the alternatives relative to the RAOs. All of the action alternatives are predicted to achieve PRGs or risk thresholds for RAOs 2 through 4. For RAO 1, the action alternatives achieve similar risk reductions, but institutional controls will be required to address remaining seafood consumption risks. All of the action alternatives use removal for the majority of the waterway, and include monitoring, maintenance, institutional controls, periodic reviews (e.g., every 5 years), and potential contingency actions to maintain effectiveness over the long term. The subsurface contaminated sediments remaining in place in capped areas have a low potential for exposure because caps are engineered to remain structurally stable under location-specific conditions. In the context of long-term effectiveness and permanence, the differences among these alternatives are primarily related to the remedial technologies used in difficult-to-access areas (e.g., underpier areas). In the limited areas that rely on ENR, in situ treatment, and MNR, residual contaminated sediment has a greater potential for future exposure and could require more monitoring and potential maintenance or contingency actions. In situ treatment is considered more permanent than ENR and MNR because in situ treatment permanently binds and reduces the bioavailability of hydrophobic organic compounds (e.g., PCBs). Removal through diver-assisted hydraulic dredging in underpier areas is also likely to leave contaminated sediment behind due to the presence of riprap slopes and debris, which may also require further maintenance or contingency actions.

As shown in Table 4, the No Action Alternative has the lowest relative rank (★) for long-term effectiveness and permanence because it would not reduce risks sufficiently to achieve RAOs, it would leave the largest amount of subsurface contamination in place, and it would not provide reliable controls. All of the action alternatives are considered highly permanent due to achieving similar risks and relying primarily on removal. Alternative 1A(12) ranks moderate (★★★) because it is predicted to have slightly higher risks in the long term (Table 4) and would remove the least amount of contaminated sediment among the action alternatives (and would leave the largest area to be managed by MNR and ENR).

Alternatives 1B(12) and 1C+(12) rank relatively higher (★★★★) because they achieve slightly lower risks compared to Alternative 1A (12), but would remove a similar

7 Other factors that influence the long- and short-term concentrations include mixing and exchange of sediment by propwash, and dredging residuals.

amount of contaminated sediment as Alternative 1A(12) and has the largest area managed by ENR and in situ treatment. Alternatives 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), and 3E(7.5) score highest (★★★★★) because they achieve similar risks among the action alternatives, and they rely primarily on removal. These alternatives have little ENR and limited areas of engineered isolation capping, which is considered highly permanent.

Reduction in Toxicity, Mobility, or Volume through Treatment

This criterion assesses the degree to which site media are treated to permanently and significantly reduce the toxicity, mobility, or volume of site contaminants. The only treatment technology retained for the remedial alternatives is in situ treatment using activated carbon. Activated carbon lowers the mobility of contaminants, reducing the toxicity and bioavailability to biological receptors.

The No Action Alternative and Alternative 1A(12) do not use treatment technologies and rank lowest for this criterion (★). The other action alternatives rank higher for this criterion for employing in situ treatment in underpier areas (★★★★★; 12 to 13 acres).

Short-term Effectiveness

The evaluation of short-term effectiveness includes the effects of the alternatives on human health and the environment during the construction phase of the remedial action and the time until RAOs are achieved (Table 4 and Figure 10). Alternatives with larger removal volumes and longer construction timeframes (particularly for diver-assisted hydraulic dredging) present proportionately larger risks to workers, the community, and the environment.

Longer construction periods increase the time that the water column is impacted by dredging operations, equipment and vehicle emissions, carbon footprint, and consumed landfill capacity. The action alternatives vary in construction duration and associated impacts from 9 to 13 years—with Alternative 3E(7.5) having the greatest risks to workers, due to the longest overall construction timeframe and considerable underwater construction period using divers in underpier areas.

The time to achieve RAOs 2 through 4 is equal to the construction duration for all of the action alternatives except Alternative 1A(12), which meets RAO 3 in 39 years from the start of construction. The action alternatives achieve similar risk reductions for RAO 1. Alternative 1A(12) is predicted to achieve 1×10^{-5} order of magnitude cancer risk for Child Tribal RME in a longer timeframe than the other action alternatives (34 years from the start of construction), while the other action alternatives achieve it at the end of construction (9 to13 years, depending on the alternative).

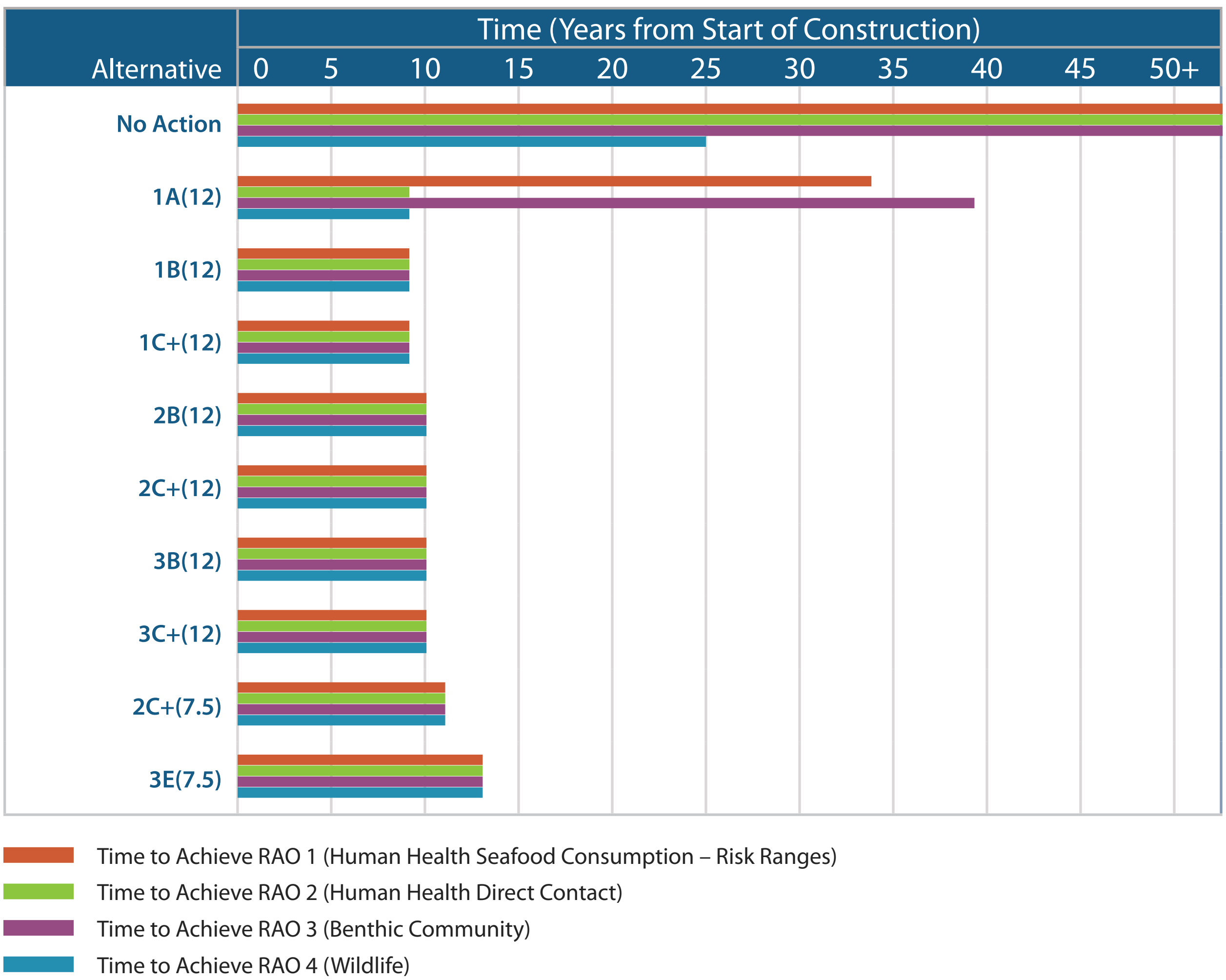
Other RAO 1 risk metrics are predicted to be achieved by the end of the construction period of the action alternatives (9 to13 years, depending on the alternative).

As shown in Table 4, the No Action Alternative has the lowest ranking (★) for short-term effectiveness because, although it has no impacts associated with construction (as no actions are included in its scope), it is not expected to achieve all of the RAOs. Alternative 3E(7.5) also ranks the lowest (★) because it has 1) the greatest short-term impacts to human health and the environment during construction, due to the amount of sediment removal and associated longer construction timeframe (13 years); 2) the highest potential for work-related accidents (due to extensive use of diver-assisted hydraulic dredging [12 years] in underpier areas), which poses substantial health and safety risks to remediation workers; and 3) has one of the longest times to achieve RAOs, among the action alternatives. Alternative 1A(12) ranks relatively low (★★) because, although it has the lowest construction-related impacts of the action alternatives, it has a longer time to achieve RAO 3 (39 years) and 1×10^{-5} order of magnitude cancer risk for Child Tribal RME for RAO 1 (34 years), due to reliance on some monitored natural recovery (which reduces risks less rapidly and considered to have less certainty than active remedial measures). Alternative 2C+(7.5) also ranks relatively low (★★) because of moderately more construction impacts compared to the action alternatives (11 years of construction; 2 years of diver-assisted hydraulic dredging) and moderately longer time to achieve RAOs (11 years). Alternatives 2C+(12) and 3C+(12) have a moderate ranking (★★★) due to the moderate construction impacts to human health and the environment (10 years of construction; 2 years of diver-assisted hydraulic dredging), and moderate time to achieve RAOs (10 years). Alternatives 1C+(12), 2B(12), and 3B(12) are ranked relatively higher (★★★★) due to lower construction impacts to human health and the environment (9 years of construction, with 2 years of diver-assisted hydraulic dredging for Alternative 1C+(12), and 10 years of construction with no diver-assisted hydraulic dredging for Alternatives 2B(12) and 3B(12), combined with moderately shorter time to achieve RAOs (9 to 10 years). Alternative 1B(12) ranks the highest (★★★★★) by having the least construction impacts among the alternatives (9 years of construction), no diver-assisted hydraulic dredging, and the shortest time to achieving RAOs among the alternatives (immediately following construction).

Implementability

Technical implementability and administrative implementability are factors considered under this criterion for the EW. Technical implementability encompasses the complexity and uncertainties associated with the alternative, the reliability of the technologies, the ease of undertaking potential contingency remedial actions, and monitoring requirements. Administrative feasibility includes the activities

Figure 10: Anticipated Timeframes to Achieve Remedial Action Objectives



required for coordination with other parties and agencies (e.g., consultation, or obtaining permits for construction activities). The action alternatives represent large, complex remediation projects with many technical and administrative challenges.

The technical implementability challenges are similar across action alternatives in open-water areas, but are different across these alternatives in underpier areas. Alternative 1A(12) has few technical challenges associated with MNR in underpier areas. The other action alternatives have larger technical challenges associated with placing in situ treatment material in underpier areas. In addition, Alternatives 2C+(12), 3C+(12), 2C+(7.5), and 3E(7.5) have large technical challenges associated with diver-assisted hydraulic dredging under piers. This form of dredging is more difficult to implement than other technologies, particularly in underpier areas, due to work conducted in deep water with low visibility and presence of suspended sediments; variable conditions under piers (e.g., presence of debris, cables, large wood, and broken pilings); potential prolonged impacts and delays to vessel operations (related to diving schedules); and extensive dewatering and water management operations. In addition, diver-assisted hydraulic dredging is a hazardous activity from a worker health and safety perspective.

For administrative implementability, all underpier technologies (MNR, in situ treatment, and diver-assisted hydraulic dredging) would be monitored following construction and have the possibility for future contingency actions if remediation goals are not met. In addition, Alternatives 1A(12), 1B(12), and 1C+(12) have a higher potential for future contingency actions in open-water areas because of ENR-nav in the navigation channel. Another administrative feasibility factor for the EW is that in-water construction is not allowed year-round, in order to protect juvenile salmon and bull trout migrating through the EW. Coordination will be necessary with stakeholders, waterway users, and agencies during design to define the limits of work each season.

Alternative 3E(7.5) receives the lowest rank (★) for implementability relative to the other alternatives, due to technical and safety challenges associated with 12 construction years of diver-assisted hydraulic dredging over large areas of underpier sediment, placement of in-situ treatment material under the piers, and it having the largest overall scope of the alternatives (13 years of construction).

Alternatives 1C+(12), 2C+(12), 3C+(12), and 2C+(7.5) receive a relatively low ranking (★★) because they employ some diver-assisted hydraulic dredging followed by in situ treatment under the piers and have moderate overall scope of remediation (9 to 11 years). Alternatives 1B(12), 2B(12), and 3B(12) are considered moderately implementable (★★★) because they perform in situ treatment in underpier areas (which is more implementable than diver-assisted hydraulic dredging) and have moderate overall scope of remediation (9 to 11 years). Alternative 1A(12), with MNR under the piers, scores the highest among the action alternatives (★★★★) because of the high implementability of performing MNR under the piers and a moderately lower overall scope (9 years of construction). The No Action Alternative is given the highest implementability rank (★★★★★) because it has no construction elements and no contingency actions assumed.

Cost

Figure 9 depicts the costs for the remedial alternatives plotted with the remedial technology areas. Alternative 3E(7.5) has the highest cost ($411 million), and therefore ranks lowest (★) for this criterion. Alternatives 3C+(12) and 2C+(7.5) are assigned a relatively low ranking (★★), with costs of $310 and $326 million, respectively. Alternatives 1C+(12), 2B(12), 2C+(12), and 3B(12) receive a moderate ranking (★★★), with costs ranging from approximately $277 to $298 million. Alternatives 1A(12) and 1B(12) receive a relatively high ranking (★★★★), with costs of approximately $256 to $264 million, respectively. The No Action Alternative has the lowest cost, at $950,000, and therefore has the highest ranking (★★★★★) for this criterion.

Cost-effectiveness

A statutory requirement that must be addressed in the ROD and supported by the FS is that the remedial action must be cost-effective (40 CFR § 300.430(f)(1)(ii)(D)). Cost-effectiveness is the consideration of both the costs and the benefits (or "overall effectiveness") for the remediation alternatives. The cost-effectiveness determination should carefully consider the relative incremental benefits and costs between the alternatives. In accordance with the National Contingency Plan, the cost of the selected remedy must not be greater than less costly alternatives that provide an equivalent level of protection (EPA 1999).[8] For the cost-

8 EPA, 1999. A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents. EPA 540-R-98-031. U.S. Environmental Protection Agency, Washington, D.C. July 1999.

effectiveness evaluation, benefits were assessed using three balancing criteria (long-term effectiveness and permanence; reduction in mobility, toxicity, or volume due to treatment; and short-term effectiveness) considered together. Figure 11 depicts long-term effectiveness and costs for the alternatives.

The least costly action alternative, Alternative 1A(12), does not rank as highly for the other balancing criteria compared to the other action alternatives, primarily due to increased time to achieve RAOs and slightly higher risks, compared to the other action alternatives. Moreover, the cost savings for this alternative are not commensurate with the decreased overall effectiveness for the alternative. While the most costly alternative, Alternative 3E(7.5), results in the largest removal volume, it does not provide a commensurate improvement in overall effectiveness relative to the other alternatives (i.e., there is no appreciable reduction in site-wide risks). Further, the incremental cost of this alternative relative to the next most costly alternative ($85 million) is disproportionate to any additional environmental benefits.

The rest of the action alternatives (Alternatives 2B(12) through 2C+(7.5)) have similar overall effectiveness, with the alternatives with only in situ treatment under the piers (Alternatives 1B(12), 2B(12), and 3B(12)) ranking slightly better than the alternatives that include diver-assisted hydraulic dredging (Alternatives 1C+(12), 2C+(12), 3C+(12), and 2C+(7.5)). The benefits among these alternatives (particularly human health risk reduction) do not increase with higher costs; therefore, lower-cost alternatives tend to be more cost-effective.

Figure 11: Long-term Risks and Costs for the Alternatives

Notes:
MM – million
RME – reasonable maximum exposure

Figure 12: CERCLA Comparative Analysis of Alternatives

	Achieve Threshold Criteria?	Long-term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-term Effectiveness	Implementability	Cost
No Action	No	Low	Low	Low	Very high	Very high
1A(12)	Yes	Moderate	Low	Low-moderate	Relatively high	Relatively high
1B(12)	Yes	Relatively high	Very high	Very high	Moderate	Relatively high
1C+(12)	Yes	Relatively high	Very high	Relatively high	Low-moderate	Moderate
2B(12)	Yes	Very high	Very high	Relatively high	Moderate	Moderate
2C+(12)	Yes	Very high	Very high	Moderate	Low-moderate	Moderate
3B(12)	Yes	Very high	Very high	Relatively high	Moderate	Moderate
3C+(12)	Yes	Very high	Very high	Moderate	Low-moderate	Low-moderate
2C+(7.5)	Yes	Very high	Very high	Low-moderate	Low-moderate	Low-moderate
3E(7.5)	Yes	Very high	Very high	Low	Low	Low

- Ranks very high compared to other alternatives
- Ranks relatively high compared to other alternatives
- Ranks moderate compared to other alternatives
- Ranks low-moderate compared to other alternatives
- Ranks low compared to other alternatives

Notes:

Low costs are given a high rank, and high costs are given a low rank.

CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act

Photo: Wikimedia (CC BY-SA 2.5 License)

Uncertainties

Decision-making on a site of the size and complexity of the EW requires careful consideration of uncertainties in the FS data and analyses. The uncertainties associated with the EW FS are similar to other large sediment remediation sites. Uncertainty is an inherent part of sediment remediation that is acknowledged and managed through monitoring and adaptive management. Many of the uncertainties in this FS affect all alternatives to a similar degree, and therefore do not significantly affect the relative comparisons of alternatives. The following factors emerge as particularly important for managing uncertainty relative to the anticipated performance of the alternatives:

- Predictions of average surface sediment contaminant concentrations are greatly influenced by a number of factors related to incoming sediment concentrations, vessel scour, and exchange of sediment between underpier areas and open-water areas.
  - » Upstream inputs, which contribute the majority of ongoing inputs to the EW, are uncertain. As a result of the large amounts of relatively clean sediments from the Green River upstream that deposit within the EW, surface sediment contaminant concentrations are predicted to converge to levels similar to the quality of incoming sediment from the Green River. (General urban inputs from EW lateral sources and the LDW will also affect long-term concentrations.) This results in similar levels of risk over time among all of the alternatives under consideration. The concentrations of these inputs are uncertain and will change over time in response to many factors, including upstream cleanups, upstream source control, and source control in the EW drainage basin.
  - » Sediment concentrations following remediation will be affected by sediment mixing depths, locations, and frequency of vessel scour throughout the waterway.
  - » The exchange of sediment between underpier areas and open-water areas is also predicted to affect the long-term site-wide SWACs within the EW.

These types of uncertainties were analyzed using sensitivity evaluations to understand their potential effects. Overall, predicted average surface sediment concentrations after remediation are more affected by these uncertainty factors than by expected differences associated with the remedial alternatives themselves.

- Technical challenges associated with the technologies for remediating underpier areas are a key uncertainty in this FS.
  - » The performance of MNR in underpier areas is less certain compared to the other remedial technologies due to its reliance on natural processes to reduce concentrations; however, MNR poses very few technical challenges.
  - » The performance of in situ treatment depends on many site-specific complex physical and chemical factors, and constructability of in situ treatment includes important technical challenges for placing and keeping material on steep slopes in difficult to access areas.
  - » Diver-assisted hydraulic dredging is associated with large uncertainty with both performance and technical implementability. Performance is uncertain with respect to the quantity of contaminated sediment that will be left behind due to conditions under piers (e.g., riprap interstices and debris).
  - » Technical implementability is also uncertain with respect to the construction timeframe and costs associated with removing underpier sediments in deep water. In particular, challenging working conditions, including deep dive depths, low visibility, presence of suspended sediments, presence of debris, cables, large wood, and broken pilings, all contribute to project uncertainty.
  - » Underpier work has the potential for prolonged impacts to vessel operations, and/or prolonged implementation times as diver work windows are narrowed to avoid vessel operations. Extensive dewatering and water management operations also present considerable logistical challenges and uncertainty. Finally, substantial health and safety risks are posed by this type of underwater construction, and management of those risks can slow the implementation or limit the areas that can be safely dredged by divers.
- The performance of the remedial technologies in open-water areas also have uncertainties, which are mitigated by adaptive management.
  - » Dredging results in the release of contaminants to the water column (in which fish and shellfish tissue contaminant concentrations remain elevated over the construction period) and deposition of dredge residuals to the sediment surface, which affects achievable sediment concentrations. In addition, structural offsets from existing waterway structures will limit the complete removal of sediments from the EW.
  - » Capping and ENR require ongoing monitoring and may need periodic maintenance.
  - » MNR and ENR performance may be slower or faster than predicted due to reliance on natural processes, and may require additional monitoring or potential contingency actions.

These uncertainties would be managed under the action alternatives through best management practices (BMPs) during construction, and in the long term through monitoring, contingency actions, and repairs as needed. Cost estimates in this FS include costs for both BMPs and long-term management activities. These activities would be enforceable requirements under a Consent Decree (or similar mechanism), and EPA is required to review the effectiveness of their selected remedy no less frequently than every 5 years.

- Uncertainty exists in the predictions of resident seafood tissue contaminant concentrations and associated human health risks for total PCBs and dioxins/furans following remediation.
  - » This uncertainty is driven by: 1) exposure assumptions from the human health risk assessment; assumptions used in the food web model for total PCBs such as uptake factors and future water concentrations; and 3) uncertainties in biota-sediment accumulation factors used for dioxins/furans.

The predictions of resident seafood tissue contaminant concentrations and risks are nevertheless useful for comparing the alternatives to one another because the uncertainties are the same for all alternatives, and therefore all of the alternatives should be affected similarly.

Conclusions

Many factors need to be considered in selecting a cleanup remedy for the EW. EPA will present a Proposed Plan for the EW for public comment, and then select the final remedy in the ROD based on input received from public, state, and tribal review of the Proposed Plan. Table 4 and Figure 12 highlight some of the key differences and similarities among the alternatives in the CERCLA comparative analysis. These similarities and differences are summarized below, along with key conclusions.

CERCLA Compliance: The action alternatives are predicted to achieve all RAOs. However, the action alternatives do not achieve natural background-based PRGs for total PCBs and dioxins/furans for RAO 1. The action alternatives will comply with the MTCA/SMS ARAR in the long term, consistent with the substantive requirements of SMS. Some MTCA/SMS and human health surface water ARARs may need to be waived regardless of the alternative based on long-term monitoring data and technical impracticability. Institutional controls will be required of all alternatives.

Removal of Contaminated Sediment: All alternatives emphasize the removal of contaminated sediment, and therefore, minimize contaminated subsurface sediment remaining in place after construction is complete. Total removal volumes increase with each consecutive alternative and range from 800,000 to 1,080,000 cy. The alternatives vary in the remedial approaches used in difficult-to-access underpier sediments. The alternatives include contingency actions if contaminant reduction does not occur at an acceptable pace as part of an adaptive management strategy. These long-term management requirements would be implemented through the requirements of a Consent Decree, and the associated costs are included in the form of limited contingencies in the FS cost estimates.

Monitoring Requirements: The action alternatives each require long-term monitoring to be protective. The alternatives differ in the total area that requires maintenance and certain types of monitoring.

Short-term Impacts throughout Construction: The action alternatives have short-term impacts such as disturbances to habitat, elevated contaminant concentrations in resident fish and shellfish tissue, worker safety concerns, traffic, air emissions related to off-site transport of dredged material, and consumption of landfill space that varies with the volume dredged. Contaminant exposures from resident seafood consumption are expected to remain elevated throughout the construction period and for a few years following construction. Short-term impacts are largely a function of the extent and duration of dredging and disposal activities. Alternatives with greater removal volumes have greater short-term impacts. Alternative 3E(7.5) has the largest safety risks to workers due to extensive diver-assisted hydraulic dredging.

Construction Timeframes: The action alternatives vary from 9 to 13 years for construction.

Predicted Time to Achieve RAOs: The predicted time to achieve RAOs is influenced by the length of time it takes to construct an alternative and the effectiveness of the remedial technologies used, particularly in underpier areas. All of the action alternatives, with the exception of Alternative 1A(12), achieve RAOs following construction. Alternative 1A(12) is predicted to achieve RAO 3 in 39 years from the start of construction. For RAO 1, all action alternatives achieve similar risk reductions, with Alternative 1A(12) taking longer to achieve 1×10^{-5} order of magnitude cancer risk for Child Tribal RME (34 years from the start of construction, while the other action alternatives achieve it at the end of construction).

Costs: The action alternatives range in costs from $256 to $411 million. All alternatives primarily use dredging; however, the lower-cost alternatives use more ENR (Alternatives 1A(12), 1B(12), and 1C+(12)) and partial dredging and capping (Alternatives 1A(12), 1B(12), 1C+(12), 2B(12), 2C+(12), and 2C+(7.5)). Higher-cost alternatives use more dredging (Alternatives 3B(12), 3C+(12), and 3E(7.5)). The highest cost alternative has the most removal and uses extensive diver-assisted hydraulic dredging in the underpier areas (Alternative 3E(7.5)).

Cost-effectiveness: A statutory requirement that must be addressed in the ROD and supported by the FS is that the remedial action must be cost-effective (40 CFR § 300.430(f)(1)(ii)(D)). The overall effectiveness of the least costly alternative, Alternative 1A(12), is less than the next higher cost alternative (particularly considering time to achieve RAOs), and thus is considered less cost-effective than the other alternatives. Similarly, while the most costly alternative, Alternative 3E(7.5), involves the greatest removal volume, it does not result in a commensurate improvement in overall effectiveness (particularly considering overall risk reduction), and thus is considered the least cost-effective relative to the other alternatives.

For the rest of the action alternatives (Alternatives 1B(12) through 2C+(7.5)), overall effectiveness is similar (particularly human health risk reduction) and does not increase with higher costs; therefore, lower-cost alternatives tend to be more cost-effective.

Uncertainties: Overall, predicted average surface sediment concentrations after remediation are more affected by uncertainty factors (e.g., chemistry of Green/ Duwamish River sediments and net sedimentation rates) than by expected differences associated with the remedial alternatives themselves. However, this analysis is performed using a common set of assumptions for all alternatives to demonstrate the differences among alternatives.


Photo: Port of Seattle

Next Steps

EPA will issue a Proposed Plan that identifies a preferred remedial alternative for the EW. After public, state, and tribal comments on the Proposed Plan are received and evaluated, EPA will select the final remedial alternative in the Record of Decision (ROD).

This FS has assumed that a period of 5 years would be required following the ROD and before the start of remedial construction. During this period, the following activities would occur:

- Completion of source control sufficiency evaluations to begin remedial actions.
- Negotiation and entry of consent decrees or issuance of administrative orders for remedial design and construction.
- Sampling to refine cleanup areas.
- Remedial design and demonstration of substantial compliance with construction ARARs.
- Site-wide sampling (for example, of sediments, surface water, and fish and shellfish tissue) to establish baseline conditions for comparison to post-remediation monitoring results.
- Implementation of institutional controls addressing seafood consumption risks under RAO 1.
- Selection of construction contractor(s) and preparation of detailed construction work plans.

EAST WATERWAY OPERABLE UNIT

SUPPLEMENTAL REMEDIAL INVESTIGATION/ FEASIBILITY STUDY

FINAL FEASIBILITY STUDY

For submittal to

The U.S. Environmental Protection Agency
Region 10
Seattle, WA

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LIST OF ACRONYMS AND ABBREVIATIONS

90/90 UTL	90% upper tolerance limit on the 90th percentile
μg	microgram
μg/kg	microgram per kilogram
μg/L	microgram per liter
μm	micrometer
AC	activated carbon
ADCP	Acoustic Doppler Current Profiler
AET	apparent effects threshold
API	Asian and Pacific Islanders
ARAR	applicable or relevant and appropriate requirement
ASAOC	Administrative Settlement Agreement and Order on Consent
BAZ	biologically active zone
BEHP	bis(2-ethylhexyl) phthalate
bgs	below ground surface
BMP	best management practice
BNSF	BNSF Railway Company
BSAF	biota-sediment accumulation factor
CAD	confined aquatic disposal
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
City	City of Seattle
cm	centimeter
cm/s	centimeter per second
cm/yr	centimeter per year
CMA	Construction Management Area
CO	carbon monoxide
CO_2	carbon dioxide
COC	contaminant of concern
COPC	contaminant of potential concern
County	King County
cPAH	carcinogenic polycyclic aromatic hydrocarbon
Cs-137	cesium-137
CSL	cleanup screening level

CSM	conceptual site model
CSO	combined sewer overflow
CT	central tendency
CWA	Clean Water Act
cy	cubic yard
DDT	dichlorodiphenyl-trichloroethane
DMMP	Dredged Material Management Program
DNR	Washington State Department of Natural Resources
dw	dry weight
EAA	Early Action Area
Ecology	Washington State Department of Ecology
EISR	existing information summary report
ENR	enhanced natural recovery
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ESD	Explanation of Significant Differences
EW	East Waterway
EWG	East Waterway Group (Port of Seattle, City of Seattle, and King County)
FS	Feasibility Study
FWM	food web model
g/cm^3	gram per cubic centimeter
g/day	gram per day
GRA	general response action
H:V	horizontal to vertical
HC	hydrocarbon
HHRA	human health risk assessment
HI	hazard index
HOC	hydrophobic organic contaminant
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
HQ	hazard quotient
I-5	Interstate 5
ICIAP	Institutional Control Implementation and Assurance Plan
IRIS	Integrated Risk Information System
JARPA	Joint Aquatic Resource Permit Application
kg	kilogram
kg/yr	kilogram per year

L	liter
LDW	Lower Duwamish Waterway
LOAEL	lowest-observed-adverse-effect level
LOEC	lowest observed effect concentration
LPAH	low-molecular-weight polycyclic aromatic hydrocarbon
M	Moment Magnitude Scale
MDL	method detection limit
mg/kg	milligram per kilogram
MHHW	mean higher high water
MIS	multi-increment sampling
MJ	megajoule
MLLW	mean lower low water
MNR	monitored natural recovery
MTCA	Model Toxics Control Act
MUDS	Multi-User Disposal Site program
NCDF	nearshore confined disposal facility
NCP	National Contingency Plan
ng	nanogram
ng/L	nanogram per liter
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no-observed-adverse-effect level
NO_x	nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NPV	net present value
NRC	National Research Council
NSR	net sedimentation rate
NTCRA	non-time critical removal action
O&M	operations and maintenance
OC	organic carbon
OSV	Ocean Survey Vessel
OU	Operable Unit
Pa	Pascals
PAH	polycyclic aromatic hydrocarbon
Pb-210	lead-210
PCB	polychlorinated biphenyl
pcf	pounds per cubic foot

PEF	potency equivalency factor
$PM_{2.5}$	particulate matter with a diameter below 2.5 micrometers
PM_{10}	particulate matter with a diameter below 10 micrometers
PMA	Port Management Agreement
Port	Port of Seattle
POTW	publically owned treatment works
PQL	practical quantitation limit
PRG	preliminary remediation goal
propwash	propeller wash
PSAMP	Puget Sound Ambient Monitoring Program
PSCAA	Puget Sound Clean Air Agency
PTM	particle tracking model
RAL	remedial action level
RAO	remedial action objective
RBTC	risk-based threshold concentration
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RL	reporting limit
RM	river mile
RMC	residuals management cover
RME	reasonable maximum exposure
RNA	Restricted Navigation Area
ROD	Record of Decision
ROW	right-of-way
SCEAM	source control evaluation approach memorandum
SCL	sediment cleanup level
SCO	sediment cleanup objective
Screening Memo	Final Remedial Alternative and Disposal Site Screening Memorandum
SCUM	Sediment Cleanup Users Manual
SD	storm drain
SDOT	Seattle Department of Transportation
SHNIP	Seattle Harbor Navigation Improvement Project
SMS	Washington State Sediment Management Standards
SO_2	sulfur dioxide
SPU	Seattle Public Utilities

SQS	sediment quality standard
SRI	Supplemental Remedial Investigation
SRI/FS	Supplemental Remedial Investigation/Feasibility Study
SRZ	Sediment Recovery Zone
STE	sediment transport evaluation
STER	Sediment Transport Evaluation Report
SVOC	semivolatile organic compound
SWAC	spatially-weighted average concentration
T-18	Terminal 18
T-25	Terminal 25
T-30	Terminal 30
T-46	Terminal 46
T-102	Terminal 102
T-104	Terminal 104
TBT	tributyltin
TEF	toxic equivalency factor
TEQ	toxic equivalent
TI	technical impracticability
TIN	triangular irregular network
TOC	total organic carbon
TRV	toxicity reference value
TSCA	Toxic Substances Control Act
TSS	total suspended solids
U&A	Usual and Accustomed
UCL95	95% upper confidence limit on the mean
UECA	Uniform Environmental Covenants Act
USACE	U.S. Army Corps of Engineers
U.S.C.	United States Code
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
VOC	volatile organic compound
WAC	Washington Administrative Code
WDFW	Washington State Department of Fish and Wildlife
WDOH	Washington State Department of Health
Workplan	SRI/FS Workplan
WQC	water quality criteria

WQS	water quality standards
WSDOT	Washington State Department of Transportation
ww	wet weight
WW	West Waterway

1 INTRODUCTION

This document presents the Feasibility Study (FS) evaluation for the East Waterway (EW) Operable Unit (OU) of the Harbor Island Superfund site. This FS is the companion document to the Supplemental Remedial Investigation (SRI; Windward and Anchor QEA 2014). The EW is located in Seattle, Washington, and extends along the east side of Harbor Island (Figure 1-1). The EW is one of eight OUs or Study Areas of the Harbor Island Superfund site (Figure 1-1), which was added to the U.S. Environmental Protection Agency's (EPA's) National Priorities List in September 1983 under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund. Under the oversight of EPA, this FS is being conducted by the East Waterway Group (EWG), which consists of the Port of Seattle (Port), the City of Seattle (City), and King County (County). The Port entered into the Administrative Settlement Agreement and Order on Consent (ASAOC) for the SRI/FS with EPA in October 2006 (EPA 2006), and subsequently entered into a Memorandum of Agreement with the City and County to jointly conduct the SRI/FS. For purposes of the SRI/FS, the EWG will be referenced as the entity implementing the SRI/FS under EPA oversight, rather than the Port.

The SRI/FS is being conducted in a manner that is consistent with the *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA 1988) and other applicable guidance. Where appropriate, the methods used in the EW SRI/FS were consistent with those used in the Lower Duwamish Waterway (LDW) RI/FS because the sites are immediately adjacent. The physical and site use differences between the LDW and the EW are summarized in the *Final Remedial Alternative and Disposal Site Screening Memorandum* (Screening Memo; Anchor QEA 2012a). The SRI/FS will ultimately lead to an EPA Record of Decision (ROD) selecting cleanup actions to address risks to human health and the environment in the EW OU.

As stated in the ASAOC (EPA 2006) and SRI/FS Workplan (Workplan; Anchor and Windward 2007), the purpose of the FS is to develop and evaluate a number of alternative methods for achieving the remedial action objectives (RAOs) and preliminary remediation goals (PRGs) at a contaminated site. This process lays the groundwork for proposing a selected remedy that eliminates, reduces, or controls risks to human health and the environment in compliance with CERCLA requirements.

This FS, as approved by EPA, is consistent with CERCLA, as amended (42 United States Code [U.S.C.] 9601 et seq.), and the National Oil and Hazardous Substances Pollution Contingency Plan (40 Code of Federal Regulations [CFR] Part 300), commonly referred to as the National Contingency Plan (NCP). Many guidance documents were considered in developing this FS, including the following:

- *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988)
- *Clarification of the Role of Applicable or Relevant and Appropriate Requirements in Establishing Preliminary Remediation Goals under CERCLA* (EPA 1997a)
- *Rules of Thumb for Superfund Remedy Selection* (EPA 1997b)
- *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002a)
- *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005)
- *A Guide to Developing and Documenting Cost Estimates during the Feasibility Study* (EPA 2000a)

1.1 East Waterway Operable Unit Study Boundary

The EW OU study boundary was established by EPA as shown on Figure 1-1. The southern EW OU study boundary is also the northern study area boundary of the LDW Superfund site. The northern EW OU study boundary extends along the western pierhead line to the north until water depths reach -60 feet mean lower low water (MLLW). The study boundary follows the approximate upper edge of this naturally occurring slope at about -60 feet MLLW, then turns to perpendicularly intersect the bulkhead along Terminal 46 (T-46) along the eastern shoreline. The east and west boundaries of the EW OU are defined as areas below mean higher high water (MHHW; e.g., below 11.4 feet MLLW), and referred to in this FS as the EW OU or site.

1.2 Purpose of the Feasibility Study

The purpose of this FS is to develop and evaluate EW-wide remedial alternatives to address the risks posed by contaminants of concern (COCs) within the EW OU. This FS is based on the results of the SRI (Windward and Anchor QEA 2014), which included the baseline ecological risk assessment (ERA; [Windward 2012a]) and baseline human health risk assessment (HHRA; [Windward 2012b]), as Appendices A and B, respectively. This FS also builds on the evaluation of remedial technologies, disposal options, and remedial alternatives that were evaluated in the Screening Memo (Anchor QEA 2012a).

The SRI assembled data to identify the nature and extent of contamination in the EW, evaluated sediment transport processes, assessed current conditions within the EW, including risks to human and ecological receptors that use the EW, and identified potential sources and pathways of contamination to EW (see Sections 2 and 3). The FS uses the results of the SRI and the baseline risk assessments to identify RAOs, develop PRGs, and develop and evaluate EW-wide remedial alternatives (see Sections 4 through 10). The FS lays the groundwork for selecting a cleanup alternative that addresses risks to both human health and the environment in compliance with CERCLA requirements.

The Screening Memo (Anchor QEA 2012a) identified and screened sediment remedial technologies (e.g., dredging, capping, etc.) that may be applicable to the EW OU. It also screened potential disposal technologies for contaminated sediment, and included preliminary remedial alternatives to narrow the range of alternatives to be considered for detailed analysis in this FS. The purpose of the Screening Memo was to efficiently eliminate remedial technologies, disposal options, and alternatives that are not practicable so the FS can focus on viable remedial alternatives. This approach is consistent with EPA RI/FS guidance (EPA 1988) and contaminated sediment remediation guidance (EPA 2005).

1.3 The Feasibility Study Process

The FS process includes several steps outlined in CERCLA guidance (EPA 1988), as well as additional considerations outlined in *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005). Consistent with the LDW FS (AECOM 2012), these general steps and considerations include the following:

- Summarizing and synthesizing the results of the SRI, including the physical conceptual site model (CSM), baseline ERA and HHRA, and related documents for the EW (Sections 2 and 3)
- Establishing applicable or relevant and appropriate requirements (ARARs), RAOs, and associated PRGs (Section 4)

- Use of sediment risk-based threshold concentrations and background concentrations for risk driver COCs in the development of PRGs (Section 4)
- Estimating areas of sediment with risk driver COC concentrations above remedial action levels (RALs)[1] that are appropriate for the application of sediment remedial approaches[2] (Section 6)
- Evaluation of remedial and disposal technologies, as first described in the Screening Memo (Anchor QEA 2012a) (Section 7)
- Evaluation of general response actions, remedial technology types, and specific process options best suited to site conditions (Section 7)
- Assembling the technology types and process options into site-wide remedial alternatives, and then completing the estimate of areas, volumes, and costs for the alternatives (Section 8)
- Completing a detailed evaluation and comparative analysis of retained remedial alternatives (Sections 9 and 10)

Under CERCLA, the FS presents, evaluates, and compares the remedial alternatives for a site. Input from stakeholders (including the Muckleshoot and Suquamish Tribes and the State) will be considered by EPA during development of the final FS. After approval of the FS, EPA proposes a final cleanup remedy in a document called the Proposed Plan; this plan is then provided to the public and stakeholders for comment. After public and stakeholder comments on the Proposed Plan are evaluated, EPA selects the final remedy in a ROD, including the final RAOs and cleanup levels based on the nine remedy selection criteria specified in the NCP (40 CFR 300.430(e)(9)(iii)).

1.4 Definitions for the Feasibility Study

Definitions of regulatory terms, contaminant concentrations, various spatial areas, and time frames used in the FS are provided below. Some of these terms have site-specific definitions, but most are drawn directly from CERCLA regulations or guidance documents. In the case of

[1] The RALs are developed in Section 6 to define areas that undergo remediation to achieve RAOs. RALs may or may not be set at the PRGs, depending on the risk pathway being addressed.

[2] The water column cannot practicably be directly remediated, but improvements in surface water quality are expected following sediment cleanup and source control measures.

new definitions, similar terms are referenced when applicable. These definitions are consistent with those used in the LDW FS (AECOM 2012).

1.4.1 Regulatory Terms

Background; CERCLA uses the terms anthropogenic (man-made) background and natural background (EPA 1997b), and EPA's sediment remediation guidance (EPA 2005) states that cleanup levels will normally not be set below natural or anthropogenic background concentrations. Washington State Sediment Management Standards (SMS; Washington Administrative Code [WAC] 173-204; Ecology 2013) use the terms regional background and natural background.

Cleanup level under CERCLA means the concentration of a hazardous substance in an environmental medium that is determined to be protective of human health and the environment under specified exposure conditions. Cleanup levels are proposed in the FS but are not finalized until the ROD.

Contaminants of concern (COCs) represent a defined set of hazardous substances that were quantitatively evaluated in the baseline risk assessments and were found to exceed risk thresholds (see Section 3 for more details).

Natural background, as defined in the SMS, represents the concentrations of hazardous substances that are consistently present in an environment that has not been influenced by localized human activities. This definition includes both substances such as metals that are found naturally in bedrock, soils, and sediments, as well as persistent organic compounds such as polychlorinated biphenyls (PCBs) that can be found in soil and sediments throughout the state as a result of global distribution of these contaminants. Whenever the term natural background is used in this FS, it means as defined in the SMS (WAC 173-204-505).

Point of compliance is defined as the point or points where cleanup levels shall be achieved.

Practical quantitation limit (PQL) is defined as the "lowest concentration that can be reliably measured within specified limits of precision, accuracy, representativeness, completeness, and comparability during routine laboratory operating conditions, using department approved methods." The NCP (40 CFR 300.430(e)(2)(i)(A)(3)) allows that cleanup levels can be modified based on "factors related to technical limitations such as detection/quantitation limits for contaminants." The term PQL is synonymous with quantitation limit and reporting limit.

Preliminary remediation goals (PRGs) are specific desired contaminant endpoint concentrations or risk levels for each exposure pathway that are believed to provide adequate protection of human health and the environment based on available site information (EPA 1997b). For the FS, PRGs are expressed as sediment concentrations for the contaminants that present the principal risks (i.e., the risk drivers). PRGs are based on consideration of the following factors:

- ARARs
- Risk-based threshold concentrations (RBTCs) developed in the SRI
- Background concentrations are used to develop PRGs if protective RBTCs are below background concentrations
- Analytical PQLs if protective RBTCs are below concentrations that can be quantified by chemical analysis

PRGs are presented in the FS as preliminary cleanup levels that are used in the FS to guide evaluation of proposed sediment remedial alternatives, but they are not the final CERCLA cleanup levels. EPA will ultimately define those levels in the ROD.

Regional background is a term defined in the SMS as the concentration of a contaminant within a Washington State Department of Ecology (Ecology)-defined geographic area that is primarily attributable to diffuse sources, such as atmospheric deposition or stormwater, not attributable to a specific source or release (WAC 173-204-505(16)).

Remedial action objectives (RAOs) describe what the proposed remedial action is expected to accomplish (EPA 1999a). They are narrative statements of specific goals for protecting human health and the environment. RAOs are used to help focus development and evaluation of remedial alternatives. RAOs are derived from the baseline risk assessments and are based on the exposure pathways, receptors, and the identified COCs. Narrative RAOs form the basis for establishing PRGs (defined above).

Remedial action levels (RALs) are contaminant-specific sediment concentrations that trigger the need for remediation (e.g., dredging, capping, enhanced natural recovery [ENR], or monitored natural recovery [MNR]). Remediation levels or RALs are not the same as cleanup levels or PRGs. Remediation levels may be used at sites where a combination of cleanup actions is used to achieve cleanup levels at the point of compliance. Remediation levels, by definition, exceed cleanup levels.

Remediation Area is the area with sediment concentrations above any of the RALs that is or could be exposed to human or ecological receptors.

Risk driver hazardous substances (risk driver COCs) are used in the FS to indicate the subset of COCs identified in the baseline risk assessments that present the principal risks. Risk drivers are a subset of hazardous substances present at a site selected for monitoring and analysis or for establishing cleanup requirements.

Other COCs not designated as risk drivers will be discussed in the FS by estimating the potential for risk reduction following remedial actions. In addition, COCs may be assessed as part of the 5-year review that is conducted every 5 years once a CERCLA cleanup is completed that leaves hazardous substances on site above cleanup levels, and they may be included in the post-cleanup monitoring program.

Washington State Sediment Management Standards (SMS) include the Washington State requirements for sediment cleanup sites and are an ARAR for the EW OU of the Harbor Island Superfund site.

Total excess cancer risk is defined as the additional probability (i.e., the additional probability above the lifetime cancer risk[3]) of an individual developing cancer over their lifetime based on exposure to site-specific contaminants. In the final EW baseline HHRA (Windward 2012b) and this FS, total excess cancer risk is defined as the sum of all cancer risks for multiple contaminants and pathways for an exposure scenario. For example, total excess

[3] The lifetime risk of developing cancer in the United States is 1 in 2 for men and 1 in 3 for women (American Cancer Society 2006).

cancer risks for the clamming scenario include cancer risks associated with the dermal exposure pathway for exposure to sediment and the incidental sediment ingestion pathway.

1.4.2 Sediment Concentrations

Sediment concentrations are expressed and evaluated in the FS in two ways: 1) as individual point concentrations; or 2) as spatially-weighted average concentrations (SWACs). RBTCs were developed in the SRI and are also expressed as either point concentrations or SWACs (all defined below).

Point concentrations are contaminant concentrations in sediments at a given sampling location, where each value is given equal weight. Point concentrations are typically applied to small exposure areas (e.g., for benthic organisms with small home ranges). Point concentrations are sometimes mapped in the FS as Thiessen polygons, with each Thiessen polygon defined as an area of influence around its sample point, so that any location inside the polygon is closer to that point than any of the other sample points. Point concentrations are compared to either dry weight-based concentration thresholds, or to organic carbon (OC)-normalized concentration thresholds, depending on the contaminant.

Risk-based threshold concentrations (RBTCs) are the calculated sediment and tissue concentrations estimated to be protective of a particular receptor for a given exposure pathway and target risk level. RBTCs are based on the baseline risk assessments and were derived in the SRI. Tissue RBTCs are used to derive sediment RBTCs that are predicted to reduce tissue concentrations to protective levels for human health seafood consumption based risks or fish and wildlife-based risks. Sediment RBTCs are used along with other site information to set PRGs (defined above) in the FS.

Spatially-weighted average concentrations (SWACs) are similar to a simple arithmetic average of point concentrations over a defined area, except that each individual concentration value is weighted in proportion to the sediment area it represents. SWACs are widely used in sediment management because they are more accurate at calculating area-wide average concentrations than arithmetic-based averages where data points are not evenly distributed. The selected area over which a SWAC would be applied may be adjusted for a specific receptor or activity. For example, EW-wide SWACs may be appropriate for estimating human health risks associated with consumption of resident seafood, but not for direct contact risks from the collection of clams (which are harvested only in certain areas). In this manner, site-wide or area-wide SWACs are intended to provide meaningful estimates of exposure point concentrations for human or ecological receptors.

SWAC calculations have been used at several large Superfund sediment sites to evaluate risks and cleanup levels (e.g., LDW, Fox River, Hudson River, Housatonic River, and Willamette River). For example, the Lower Fox River ROD selected a total PCB remedial action level of 1 milligram per kilogram (mg/kg) dry weight (dw) in sediment to achieve a site-wide SWAC of 250 micrograms per kilogram (μg/kg) dw over time.

95% upper confidence limit on the mean (UCL95) is a statistically derived quantity associated with a representative sample from a population (e.g., sediment or tissue chemistry results from a waterbody) such that 95% of the time, the true average of the population from which the sample was taken will be less than the quantity statistically derived from the sample dataset (e.g., 95% of the time, the true average sediment contaminant concentration for the waterbody will be less than the UCL95 based on sediment chemistry sample results). The UCL95 is used to account for uncertainty in contaminant concentrations and to ensure that contaminant concentrations are not underestimated.

1.4.3 Terms Related to Time Frames

The remedial alternatives refer to different time frames when describing different aspects of the remedy, such as the number of years to design or implement a remedy, or the number of years to achieve the RAOs. For clarity, the terms related to time frames used in the FS are defined below.

Construction period refers to the time assumed necessary to construct the remedial alternatives. For the EW, this period is assumed to begin 5 years following issuance of the ROD to allow sufficient time for priority source control actions; negotiation of orders or consent decrees; initial remedial design and planning, including remedial design sampling and analysis; baseline monitoring; and permitting and obtainment of authorizations.

Monitored natural recovery (MNR) period is the time during which the MNR-specific level of monitoring is needed in MNR areas. Monitoring conducted during the MNR period will assess whether sufficient progress is being made toward achieving cleanup objectives, or, alternatively, whether contingency actions (which may include modifying technologies or methods of applications) are warranted to meet the project goals (e.g., the SMS).

Natural recovery is a term used in this FS to describe the time after remediation during which natural recovery processes are expected to continue reducing surface sediment concentrations toward natural background-based PRGs. Natural recovery is tracked by site-wide monitoring; however, unlike MNR, natural recovery does not include location-specific monitoring or contingency actions.

1.5 Document Organization

The remainder of this document is organized as follows:

- Section 2 (Environmental Setting, SRI Summary, and Current Conditions) builds on the key findings of the SRI and focuses on the site characteristics that affect the selection of remedial technologies and assembly of alternatives. The FS dataset, which is the same dataset included in the SRI, is summarized in this section.
- Section 3 (Risk Assessment Summary) summarizes the results of the baseline ERA (Windward 2012a) and HHRA (Windward 2012b) and the RBTCs for risk drivers, which were derived in the SRI.
- Section 4 (Remedial Action Objectives and Preliminary Remediation Goals) presents the recommended RAOs, ARARs, and identifies PRGs for the FS.
- Section 5 (Predictive Evaluation Methodology for Site Performance Over Time) presents the framework and analysis of sediment movement in the EW and describes the methods for predicting changes in sediment chemistry.
- Section 6 (Remedial Action Levels) presents the RALs and corresponding COC footprints.
- Section 7 (Identification and Screening of Remedial Technologies) screens a broad array of remedial approaches and identifies representative technologies that may be applied to the site.

- Section 8 (Development of Remedial Alternatives) describes EW-wide remedial alternatives designed to achieve the RAOs.
- Section 9 (Detailed Analysis of Alternatives) screens the remedial alternatives individually using CERCLA guidance. The risk reduction achieved by each remedy is also discussed.
- Section 10 (CERCLA Comparative Analysis) compares the remedial alternatives on the basis of CERCLA evaluation criteria.
- Section 11 (Conclusions) summarizes the key findings of the FS and presents a general remedial approach for cleaning up the EW.
- Section 12 (References) provides publication details for the references cited throughout the text.

Tables appear within the text after first mention, and figures appear at the end of each section. Details that support various analyses in the FS are presented in the appendices, as follows:

- Appendix A: Supplemental Information for Selection of PRGs
- Appendix B: Sediment Modeling Memoranda
- Appendix C: Remediation Area Evaluation
- Appendix D: Cap Modeling
- Appendix E: Cost Estimate
- Appendix F: Volume Calculations
- Appendix G: Monitoring Program
- Appendix H: Remaining Subsurface Contamination
- Appendix I: Short-term Effectiveness Metrics
- Appendix J: Detailed Calculations and Sensitivity Analyses for Predictive Evaluation of Site Performance Over Time and Recontamination Potential
- Appendix K: Direct Atmospheric Deposition Evaluation
- Appendix L: Alternatives Screening

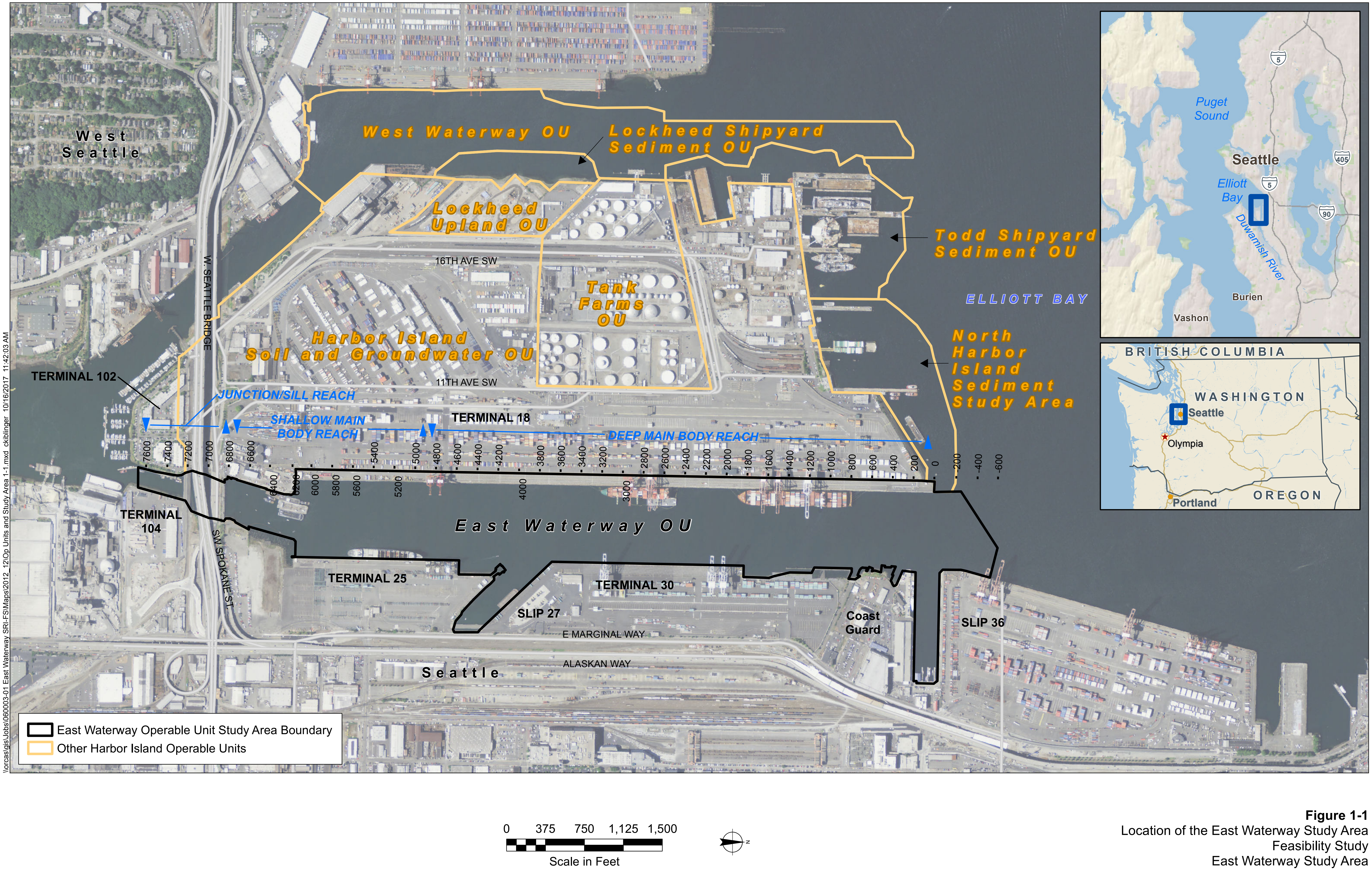

Figure 1-1
Location of the East Waterway Study Area
Feasibility Study
East Waterway Study Area

2 ENVIRONMENTAL SETTING, SRI SUMMARY, AND CURRENT CONDITIONS

This section summarizes the EW environmental setting, history, and key findings of the SRI relevant to the FS. Additional details beyond those summarized in this section are presented in the SRI (Windward and Anchor QEA 2014).

2.1 Environmental Setting

The EW is located approximately 1 mile southwest of downtown Seattle, in King County, Washington (Figure 1-1). It is part of the greater Green/Duwamish River estuary, which includes the freshwater/saltwater interface extending as far as 10 miles upstream, through the LDW, from the mouth of the EW at Elliott Bay. The EW is primarily used for shipping and as a cargo transport terminus. Detailed descriptions of EW land and waterway use are provided in Section 2.9.

The Green/Duwamish River drains approximately 362,000 acres of the Green/Duwamish watershed, flowing northward to its terminus in Puget Sound at Elliott Bay. The last 6 miles of the river were straightened and channelized into a commercial waterway for ship traffic, and is designated the LDW for approximately 5 miles, starting at the southern terminus of Harbor Island. After this point, the LDW splits into the EW and the West Waterway (WW), surrounding Harbor Island. The EW and WW extend from the southern end of Harbor Island to the island's northern end at Elliott Bay. The EW runs along the eastern shore of Harbor Island.

The EW OU of the Harbor Island Superfund site is located immediately downstream from, and adjacent to, the LDW Superfund site. The northern and southern study area boundaries for the EW OU are shown in Figure 1-1. The east and west boundaries of the EW OU are defined by MHHW, which is equivalent to 11.4 feet MLLW.

The EW OU is approximately 8,250 feet long and for most of its length is 750 feet wide. It is channelized and has a south-to-north orientation. The Port uses a measurement system along the length of the Terminal 18 (T-18) berth face, comprised of "stationing" or "station markers." The system is measured in feet from the northern end of Harbor Island (Station 0) to near the southern end of the EW (Station 7700) and is used by the Port to define the extents of the berths. The station markers are shown on Figure 2-1 and referenced throughout this FS.

Two slips are present along the eastern side of the EW. Slip 36 is oriented in an east/west direction and located from approximately Stations -100 to 200. Slip 27 is oriented in a northwest/southeast direction and located from approximately Stations 3800 to 4600. A shallow area off the northwest corner of Terminal 25 (T-25) and adjacent to Slip 27 is referred to as the “Mound Area” (Figure 2-1).

For the purposes of the SRI/FS, the following three reaches have been identified in the EW (Figure 2-1):

- **Junction Reach (Stations 7200 to 7650)**, which is the southern portion of the OU that adjoins the LDW
- **Sill Reach (Stations 6800 to 7200)**, which is a relatively shallow section of the OU just north of the Junction Reach
- **Main Body Reach (Stations 0 to 6800)**, which is north of the Sill Reach and comprises most of the EW OU

The Main Body Reach has been further subdivided into the following two sections (Figure 2-1):

- **Deep Main Body Reach (Stations 0 to 4950)**, with an authorized depth of -51 feet MLLW
- **Shallow Main Body Reach (Stations 4950 to 6800)**, which is located south of historical maintenance dredging activities and is generally shallower with an authorized depth of -34 feet MLLW

The Junction and Sill reaches are frequently discussed in combination in this report and are sometimes referred to as the Junction/Sill Reach. Recent EW dredge history is discussed in Section 2.14.3.

2.2 Site History and Current Configuration

Industrial development of the EW began immediately following the channelization of the Duwamish River and filling of surrounding Elliott Bay tidelands. Prior to filling, the Elliott Bay tidelands extended east of the site to the current location of Interstate 5 (I-5). Figure 2-2 depicts the approximate extent of the tidelands adjacent to the EW and tidelands associated with the historical meanders of the lower Duwamish River. Dredging of the Elliott Bay tidelands from 1903 to 1905 created the EW, which provided some of the fill materials for construction of the upland areas to the west (Harbor Island) and east (EPA 1993). By 1909, Harbor Island and the land east of the EW was created using dredge fill removed from the Duwamish River or sluiced from Seattle regrade projects (EPA 1993).

The construction of Harbor Island allowed further development of the EW. The EW was initially dredged to a minimum navigable depth of -30 to -40 feet MLLW and widened to 750 feet. Slip 27 was created along the eastern shore and dredged to a depth of -28 feet MLLW. By 1919, the EW, WW, and LDW were authorized as federal navigation channels by Congress (March 2, 1919). The EW was maintained at -40 feet MLLW along most of the 750-foot-wide portion in the mid-1920s. Slip 36 was constructed in 1927 and originally dredged to -35 feet MLLW.

The federal navigation channel information is based on information in the Water Resources Development Act, as summarized in the Port of Seattle Series No. 36 (USACE 2002). The federal navigation channel in the EW currently extends from beyond the north EW study boundary to the Spokane Street Bridge, which is approximately Station 6840 (Figure 2-1). The federal navigation channel is 450 feet wide from Stations 0 to 4950. It is 700 feet wide from Stations 4950 to 6140 and 400 feet wide from Station 6140 to the Spokane Street Bridge (Station 6840). The full federal navigation channel width is authorized to -51 feet MLLW from Stations 0 to 2970 (450 feet wide). It is also authorized to -51 feet MLLW along the western 250 feet from Stations 2970 to 3250 and the western 170 feet from Stations 3250 to 3590. The federal navigation channel is authorized to -34 feet MLLW south of Station 2970. This -34-foot-wide section is 200 feet wide from Stations 2970 to 3250, 280 feet wide from Stations 3250 to 3590, and 450 feet wide from Stations 3590 to 4950. South of Station 4950, it is authorized at -34 feet MLLW to the Spokane Street Bridge.

2.3 Bathymetry

The most recent bathymetric survey within the EW was completed in January 2010 and is presented in Figures 2-3a and 2-3b. Cross-sections demonstrating representative portions of each reach and slip are presented on Figures 2-4a through 2-4d. Current bathymetry within the federal navigation channel shows that the authorized elevation of -51 feet MLLW is met (or deeper) from Station 0 (i.e., mouth of the EW) to Station 4950 (i.e., 4,950 feet upstream of the mouth of the EW), with the exception of the “Mound Area.” Some areas within the northern portion of the federal channel reach -60 feet MLLW. Bathymetry in areas north of the northern EW OU study boundary (i.e., within Elliott Bay) quickly become much deeper than -60 feet MLLW, reaching elevations deeper than -200 feet MLLW. Along T-18, elevations south of Station 4950 generally decrease to -37 feet MLLW or shallower. Along T-25 (Stations 4600 to 6150), elevations in the berth area are approximately -50 feet MLLW.

Mudline elevations rise to between -13 and -6 feet MLLW in the Sill Reach, in the vicinity of Spokane Street and the West Seattle Bridge (DEA 2010), and then drop to -25 feet MLLW through the Junction Reach. Sediments comprising the Sill Reach under and between the bridges within the Spokane Street corridor have never been dredged following original construction, based on historical records from the U.S. Army Corps of Engineers (USACE). The shallow water depths in this area form a physical constriction across the entry to the EW that can affect flow from the Duwamish River primarily during higher flow events.

Current Port operational berthing elevation requirements vary based on location in the EW. Along T-18 between Stations 0 and 4950, the berthing elevation requirement is -51 feet MLLW. Along T-25 and Terminal 30 (T-30), berthing elevation requirements are -50 feet MLLW. The Port’s requirement for berthing in Slip 27 is generally -40 feet MLLW. In Slip 36, U.S. Coast Guard (USCG) berthing requirements are generally -40 feet MLLW. Dredging activities conducted since 2000 to maintain required navigation and berthing elevations are described in Section 2.14.3.

2.4 Aquatic Ownership

The main body of aquatic land in the EW is owned by the State of Washington and managed by the Washington State Department of Natural Resources (DNR) between the pierhead lines (Figure 2-5). Land located within the pierhead line is state-owned but managed by the Port through a Port Management Agreement (PMA). This area includes all aprons that extend approximately 100 feet from the Port's upland parcel boundary.

Portions of the aquatic area within the EW are not state-owned. South of the Spokane Street corridor, the Port owns the entire width of the EW. The Port also owns all of Slip 27, including the vacated portion of the South Forest Street right-of-way (ROW) and Pier 27 (south side of Slip 27). A portion of aquatic area along Pier 24 that formerly contained timber decking is also owned by the Port. All of Slip 36 is owned by USCG.

2.5 Hydrodynamics

The EW is primarily saltwater, but receives freshwater flows from the Green/Duwamish River watershed. Hydrodynamic circulation in the EW is controlled by tidal exchange with Elliott Bay to the north and freshwater inflow from the Green River (through the LDW) from the south. The EW can be generally described as two-layer flow, with a wedge of saltwater extending from Elliott Bay upstream through the EW and into the LDW underneath a layer of fresher water flowing from the Green River.

The EW also receives freshwater discharges from 39 outfalls (Figure 2-1). The discharges are intermittent, and the relative contribution of freshwater flows from the outfalls is small in comparison with flows from the Green/Duwamish River. A complete summary of the hydrodynamic modeling conducted in the EW is included in the Sediment Transport Evaluation Report (STER; Anchor QEA and Coast & Harbor Engineering 2012) and summarized in the SRI (Windward and Anchor QEA 2014). The evaluation of solids loading from the various water sources is presented in Section 5.

The EW is subject to tidal forcing from Elliott Bay, which is characterized by mixed semi-diurnal tides (two high and two low tides per day that are not equal in height). The average tidal range (MLLW to MHHW) measured at the Seattle waterfront is 11.4 feet. The highest and lowest expected tidal heights are +13 and -3.5 feet MLLW, respectively (National Oceanic and Atmospheric Administration [NOAA] Station ID 9447130).

2.6 Sediment Characteristics and Stratigraphy

A summary of surface and subsurface existing grain size, total solids, and total organic carbon (TOC) data is presented in the SRI (Windward and Anchor QEA 2014). These data indicate that most sediment samples consisted primarily of clay and silty sand, with an average of approximately 40% sand and 50% fines[4] (total silt and clay). More fines are present in sediments in the central and northern portions of the EW than in the vicinity of the Spokane Street corridor (Figure 2-6), due to shallower water and higher tidal velocities in the Spokane Street corridor. Total solids content is generally between 40% and 60% in surface and subsurface sediment. Surface sediments contain less than 2% TOC over nearly all of the EW, with a mean of 1.6% and small areas with TOC above 2%, including Slip 27 (Figure 2-7). Generally, TOC values in the subsurface layers remain similar to surface sediments throughout the upper 5 feet, but drops to a mean 0.7% in sediment deeper than 5 feet below mudline.

Not all areas of the site below MHHW contain sediment, as shown on Figures 2-6 and 2-7. Underpier areas are armored with riprap and generally contain sediment only in the lower portions of the slope. The extent of sediment has been mapped using jet probe transects[5] conducted in 1997 and 1998 along T-18, and in 2000 along T-25 and T-30. The extent of sediment in underpier areas in Slips 27 and 36 were estimated by comparing current bathymetry to design or as-built drawings for the armored underpier slopes.

2.6.1 Grain Size Composition

2.6.1.1 Surface Sediment

Surface sediment (i.e., the top 10 centimeters [cm]) primarily consists of silty sands and sandy silts. Measured sand fractions range from 8% to 95% with a mean concentration of 50%; fines (silt and clay) fractions range from 1% to 92% with a mean concentration of 40%. The majority of the samples (93%) contain various amounts of gravel ranging from 0.01% to

[4] Site-wide, the standard deviation for fines is 23%.

[5] Jet probing is conducted by a diver using probe with a jet of water. The jet of water allows the probe to penetrate deeper into the sediment by loosening compacted sediment below the mudline. The jet probe transects provide elevations and locations of exposed (i.e., not buried by sediment) riprap along the slope and the lower extent of buried rock along the slope under the pier.

68%, with a mean concentration of 8%. Spatially, the Deep Main Body Reach contains lower portions of fines (less than 60% fines) with the exception of a few areas between Stations 2000 to 3400 with higher percent fines (greater than 60% fines). Higher fines percentages tended to occur within the Shallow Main Body Reach, at the eastern end of Slip 36, and the northern portion of Slip 27 and vicinity. The fines content of surface sediment tends to be low in the Junction and Sill Reaches.

2.6.1.2 Subsurface Sediment

Available subsurface sediment (i.e., deeper than 10 cm) physical characteristics are summarized by the stratigraphic groupings and layers (see Section 2.6.2). Areas with engineered fill, anthropogenic fill, and sand cover layers (typically shallow, upper 1 foot below mudline) contain all grain sizes, but were predominantly composed of sand and gravel. The recent and upper alluvium units (0 to 5 feet below mudline) primarily consist of fines (silt and clay) with the percent of sand increasing with depth. Gravel-sized particles (including shells) are primarily present in the upper layers (i.e., 0 to 3 feet below mudline). Below 5 feet in the lower alluvium, grain size primarily consists of sand with lesser amounts of fines than upper units and trace amounts of gravel.

2.6.2 Stratigraphy

Sediment was grouped into three stratigraphic units identified for the EW based on multiple lines of evidence, but primarily on density, color, sediment type, texture, and fill horizons (e.g., sand cover). Other information used to delineate these units included presence of anthropogenic or engineered materials, bathymetry, proximity to shoreline, and dredge history. The three units are comparable to the stratigraphy identified in the LDW RI, but differ slightly in composition based on the deltaic setting of the EW (Windward 2010a). EW sediment typically includes softer, recent sediments (i.e., silt) overlying alluvial, deltaic sediments that overlie deeper alluvial, deltaic deposits associated with early and pre-industrial time periods. In some areas, dredging and site use have altered the depths at which these units outcrop compared to initial deposition. For example, the deeper alluvial units were identified in the surface in several cores collected from the Deep Main Body Reach, which is more frequently dredged and to deeper depths than other portions of the site. The primary stratigraphic units are described in detail below, from top (i.e., mudline) to bottom of core.

- **Recent –**This upper unit consists of recently deposited material dominated by unconsolidated organic silt and inorganic silt. The surface fraction of silt often contains fine sand and gravel. This material is characterized by higher moisture content, soft to medium stiff density, smooth and homogenous texture, and higher visible organic matter compared with the underlying materials. Shell fragments, decomposed wood, and anthropogenic materials are present scattered throughout the unit (rather than in distinct layers as is common in lower units). A hydrogen sulfide odor was common in the samples, typical of reduced conditions. The Recent unit is encountered in subsurface cores between 0 and 10 feet below mudline.
- **Upper Alluvium/Transition**[6] **–** This middle unit forms a transitional bed between Recent and Lower Alluvium units. The Upper Alluvium unit has characteristics that are often a mix of the units lying above and below it. It consists of a mixture of silty sand and sandy silt matrices with a higher density and a higher percentage of sand compared with the Recent unit. Within this layer, stratified beds composed of silty sand or silt are present, as well as lenses (pockets) of silt. Organic silt, layers of decomposed wood, and shell fragments were often present in the samples. Some multicolored sand grains (e.g., red, beige, black, white, and gray) are located within the units. The Upper Alluvium unit is encountered in subsurface cores between 0 and 9 feet below mudline.
- **Lower Alluvium/Native**[7] **–** This basal unit is predominantly a sand matrix with laminated and stratified beds of slightly silty to silty sand, and silt. The sand matrix consists of multicolored grains of red, beige, black, white, and gray. Layers of undecomposed wood and shells were often present in the samples. The Lower Alluvium sand unit typically grades to stiff, inorganic silt as depth increases. This unit is encountered between 0 and 13 feet below mudline.

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[6] The term Upper Alluvium is synonymous with the term Transition used in the subsurface sediment data report (Windward 2011).

[7] The term Lower Alluvium is synonymous with the term Native used in the subsurface sediment data report (Windward 2011).

In addition to the primary stratigraphic units, three veneers overlie the existing sediment stratigraphy in discrete locations. These veneers are described below:

- **Engineered Fill** – This layer was present in cores located in close proximity to the shoreline. The composition of Engineered Fill was dominated by light to dark gray, sub-rounded, gravelly sand and sandy gravel. Gravel and cobbles were up to 3 inches in diameter. Engineered Fill has been designated based on proximity to known developmental activities associated with slope and keyway armoring activities.
- **Anthropogenic Fill** – This layer was present in cores located in close proximity to the shoreline. The composition of Anthropogenic Fill is gray to black, sub-rounded gravelly sand to coarse gravel. Anthropogenic Fill has been designated where no known development activities have occurred on the slope.
- **Sand Cover –** The sand cover was placed between Stations 3000 and 4900 during the Phase 1 removal, which was completed in 2005 (Anchor and Windward 2005). Sand cover is present in the top 1 foot of cores collected from this area. The sand cover is primarily very fine to very coarse-grained brown sand that was distinctly different in appearance from other strata within the EW based on observations of color and sorting.

2.7 Hydrogeology

The hydrogeology of the EW has been influenced both by natural and anthropogenic events (e.g., channel straightening, dredging, and filling), especially channelization of the EW and placement of fill in the east and west uplands. The EW is a channelized portion of the Green/Duwamish River delta. It is located at the north end of the Greater Duwamish Valley, and rests in a north-south trending, glacially scoured trough bounded by glacial drift uplands deposited during repeated Pleistocene glaciations (approximately 15,000 years ago). The trough contains post-glacial alluvium up to 200 feet thick (Weston 1993). The trough is bounded by upland plateau regions composed of thick sequences of Pleistocene glacial deposits.

The aquifer in the vicinity of the EW is a shallow, unconfined aquifer within fill and alluvial, deltaic, and estuarine sediments. Shallow groundwater in the adjacent nearshore areas flows primarily toward the EW and Elliott Bay. Most of the fill in the east and west uplands is hydraulic fill dredged from the channel of the Duwamish River, estimated to be 15 to 35 feet below ground surface (bgs) in the east uplands and between 3 to 15 feet bgs in the west uplands (Harbor Island). Beneath the alluvium, very dense, till-like glacial sediments were measured at depths ranging from approximately 115 to 135 feet bgs (GeoEngineers 1998). Groundwater in the nearshore environment is generally characterized as follows:

- Freshwater overrides denser saltwater and thereby confines freshwater discharge to the upper portion of the aquifer near MLLW
- Upland groundwater mixes with saline groundwater prior to discharging at the shoreline, meaning that there is little to no direct discharge of freshwater to the EW; rather it is all tidally mixed
- Tidal influx results in dilution and attenuation of groundwater between nearshore wells and the shoreline

2.8 Existing Structures and Shoreline Conditions

The EW shoreline is highly developed, primarily composed of over-water piling-supported piers, riprap slopes, seawalls, and bulkheads for industrial and commercial use. Throughout the entire length of the EW, approximately 60% of the EW shoreline contains over-water piers (aprons) above riprap slopes (along T-18, T-25, T-30, T-46, and in Slips 27 and 36; see Figures 2-8 through 2-10). Another 30% contains exposed shoreline, nearly all of which is armored with riprap (including the entire area south of the Spokane Street Bridge corridor; Figure 2-8). A portion of the shoreline area does contain some small unarmored areas below the extent of armor. The remaining 10% is comprised of steel sheetpile bulkheads (Figure 2-8). The Existing Information Summary Report (EISR) provides details on existing structures and utility information (Anchor and Windward 2008a).

The Screening Memo describes critical site restrictions that affect implementability of specific remedial technologies, including site access, physical obstructions and structural conditions, water depths, and navigation and other site uses (Anchor QEA 2012a). Based on these factors, Construction Management Areas (CMAs), which represent similar site restriction conditions, were presented in the Screening Memo (Anchor QEA 2012a) and are further discussed in regard to implementability constraints during development of remedial alternatives in Section 7.

The shoreline within Slip 27 and Slip 36 is predominantly armored riprap with extensive pier structures, although the southern shore of Slip 27 has an adjacent intertidal bench that was constructed during re-armoring of the Port property. A limited number of small areas of exposed intertidal sediment are present above the riprap slopes in locations along the eastern shoreline of the waterway, including at the head of Slip 27 (Figure 2-11).

The typical concrete wharves along the Main Body Reach in the EW are 100 feet wide from the outer edge (fender line) to the inner bulkhead, which intersects the mudline at +9 feet MLLW. Areas below the bulkheads are typically engineered riprap slopes to approximately -50 feet MLLW (with some areas to -40 feet MLLW). Representative engineered riprap slopes are shown on Figure 2-9 (T-18) and Figure 2-10 (T-25 and T-30).

Four bridge structures pass over the southern end of the EW in the Spokane Street Bridge corridor (Figure 2-8). These are operated and maintained by the Seattle Department of Transportation (SDOT; Spokane Street Bridge and SW Klickitat Way between Terminal-102 [T-102] and Terminal [T-104]), Washington State Department of Transportation [WSDOT; West Seattle Bridge], and BNSF Railway Company [BNSF] [Railroad Bridge immediately adjacent to SW Klickitat Way]). A 34-foot-wide truck bridge is also present across the head of Slip 27 between T-25 and T-30. Further information on existing structures is contained in the EISR (Anchor and Windward 2008a) and Screening Memo (Anchor QEA 2012a). In the vicinity of the bridge structures, a combined sewer transfer line that crosses the EW is buried approximately 24 feet below the mudline (HDR 1997).

A communication cable crosses the EW between T-18 and the northern portion of T-30 (Figure 2-1). This cable was originally buried between -61 and -66 feet MLLW in 1972 in an armored trench. The location shown on Figure 2-1 is based on design drawings; however, this location slightly changed following repair due to a vessel anchor incident at T-18. Along T-18, the approximate crossing was located at Station 1850. Along T-30, the approximate crossing location is indicated by a visible marker on the shore at Station 1550. Mudline elevations in the footprint of the cable crossing range from -53 to -59 feet MLLW (2 to 8 feet below mudline) in the federal channel and berth areas (Oates 2007). This area is designated as a unique CMA (see Section 7) due to the presence of the communication cable, which affects assumptions for some remedial technologies in this area.

The extensive shoreline development and utility crossings in the EW affect the remedial alternatives that could be practicably implemented. The distribution and types of overwater and in-water structures within the EW are important to consider in this FS because they represent areas where:

- Pile-supported structures, engineered or non-engineered steep slopes, vertical bulkhead walls, outfall structures, and cables may be damaged or undermined by sediment remediation, such as removal.
- Remedial alternatives need to be engineered to allow navigation depths to be maintained.
- Piles and unused or dilapidated structures (e.g., bulkheads or docks) may need to be removed or modified to implement the remediation.
- Remediation may be difficult because of restricted access, presence of vessels, and armored conditions of the sediment and shoreline.
- Vessel maneuvering associated with commercial EW activities can cause scour.
- Outfalls may require armoring of adjacent sediment caps or backfill material to prevent undermining during removal actions.

2.9 Adjacent Land and Waterway Uses

2.9.1 Adjacent Facilities and Infrastructure

The EW is an active industrial waterway used primarily for container loading and transport. Land use, zoning, and land ownership along the EW are consistent with active industrial uses (Figure 2-5). The sides of the EW contain hardened shorelines with extensive overwater structures, commercial and industrial facilities, and other development.

Thirty-nine outfalls are present in the EW, including 36 storm drains (SDs), one combined sewer overflow (CSO), and two CSO/SDs (Figure 2-1). The two outfalls that are shared by separated SDs and CSOs are the Hinds and Lander CSO/SDs. These CSO/SD outfalls and the Hanford CSO outfall discharge along the eastern shoreline of the EW. The stormwater-only outfalls are located along both sides of the waterway.

2.9.2 Navigation and Berthing

The EW north of the Spokane Street corridor experiences regular vessel traffic of various sizes and types. Most vessel traffic consists of container vessels and assorted tugboats moving into and out of the EW. Each container ship requires at least one tugboat to maneuver the ship during docking and undocking. Container ships berth at T-18, T-25, and T-30 (Figure 2-5). Cruise ships also frequented the EW from 2002 to 2008, when the southern portion of T-30 was being used as a cruise ship terminal.

Numerous barges and tugboats are moored at the head of the EW along what is currently Harley Marine Services, which includes Olympic Tug and Barge as a subsidiary (Figure 2-5). At the northeast end, along T-18, tug and barge traffic utilize the Kinder Morgan petroleum products transfer facility (Figure 2-5).

Additional navigation and berthing occurs in Slips 27 and 36. Slip 27 is used by the Port for temporary moorage of barges (along Pier 28), which are maneuvered by tugboats. USCG vessels frequent Slip 36, which serves Pier 36 (south) and Pier 37 (north). USCG moors numerous vessels in Slip 36, including USCG icebreakers, cutters (longer than 65 feet), and gunboats. Only USCG vessels currently use this slip regularly, but the U.S. Navy occasionally uses this slip.

South of the Spokane Street corridor, recreational, and commercial boats access the Harbor Island Marina (T-102) from the LDW. Along the T-102 shoreline within the EW, the Port leases out moorages on a 750-foot-long dock for commercial use. The Spokane Street corridor itself prohibits any type of boat passage, except at low tide by small, shallow-draft boats (e.g., kayaks and skiffs).

USACE completed a draft Seattle Harbor Navigation Improvement Project (SHNIP) Feasibility Report and Environmental Assessment in August 2016 (USACE 2016). Several alternatives for deepening and widening the federal navigation channels in the EW and WW were evaluated. The draft recommended plan includes the deepening and widening of the federal navigation channels in both the EW and WW. Within the EW, the recommended plan would deepen and widen the entrance channel north of Station 0 and the navigation channel south to Station 4950. The Seattle Harbor Navigation Improvement Project

Feasibility Report and Environmental Assessment is expected to be finalized in mid-2018. Harbor deepening and widening is a potential future condition for the EW; however, no decision has been made to proceed with the recommended navigation improvement project for either the EW or WW, as implementation depends on approval and funding by the federal government and other parties. All alternatives in the Seattle Harbor Navigation Improvement Project Feasibility Report and Environmental Assessment assume that any deepening activities would occur following cleanup of the EW. Further, any of the EW remedial alternatives presented in this FS are compatible with the potential navigation improvement alternatives presented in the USACE report. A requirement of the navigation improvement project is that it will not reduce the environmental protectiveness of the remedy in the EW. The potential navigation improvement project is discussed further in the context of the remedial alternatives in Section 8.3.4.

2.9.3 Tribal and Recreational Use

The EW is part of the Suquamish and Muckleshoot tribes' Usual and Accustomed (U&A) fishing grounds; consequently, they reserved their rights under federal treaties to harvest salmon in commercial quantities from this area and use the waterway for a ceremonial and subsistence fishery.

The EW is used by the tribes as a resource and for cultural purposes. Currently, the Suquamish and Muckleshoot Tribes conduct a commercial netfishery in EW for salmon. Tribal fishermen can also engage in clamming activities (by means of boat access) in all intertidal areas of the EW (Figure 2-11), as well as subtidally for geoducks (currently geoducks are not being harvested from the EW).

Individuals other than tribal members are known to collect fish and crab from EW despite existing fish advisories. Although there are currently fish advisories posted (no consumption is advised for resident seafood, limits are advised for certain salmon species,[8] and no limits are posted for squid), fishing and crabbing are conducted from the north side of the Spokane Street Bridge, especially during summer and fall salmon runs and seasonal squid migration into Elliott Bay. Fishing has also been observed north of the eastern side of the Spokane

[8] Advisories for salmon are the same as those for Puget Sound.

Street Bridge from the riprap slopes during summer salmon runs. The potential clamming area for the general public is small because there are only two places where the public can gain access to intertidal areas of the EW (Figure 2-11). It is unknown if the general public is currently harvesting clams.

The EW is not a major area for recreational use compared to other waterbodies in and around Seattle (King County 1999). Recreational boating in the EW occurs on a limited basis. No boat ramps are present in the EW, but water access is provided at Jack Perry Memorial Shoreline Public Access (on the eastern side of the EW, south of Slip 36) for kayakers and other hand-launched non-motorized watercraft (e.g., canoes or rafts). Harbor Island Marina moorages in the EW are mostly used for commercial boats, but small recreational boats may enter from the LDW. The presence of the Spokane Street Bridge and the Railroad Bridge prohibit most boat passage, except at low tide by small, shallow-draft boats (e.g., kayaks and skiffs).

Few data have been located quantifying the frequency with which people use the EW for recreational purposes other than fishing. Few people, if any, engage in water activities such as swimming or scuba diving within the EW. Such uses are likely to continue to be limited by the active commercial use of the EW, the very limited public access due to security requirements of container terminals and the USCG facility, and the availability of nearby areas that provide superior recreational opportunities.

2.9.4 Ecological Habitats and Biological Communities

2.9.4.1 Habitat Types

Dredging and development since the early 1900s have substantially altered nearshore environments in Elliott Bay and the Green/Duwamish River. Prior to the channelization and industrialization of the Duwamish River, the habitat associated with the river's mouth was predominantly an intertidal/shallow subtidal estuarine mudflat. Since the creation of Harbor Island, all of the original habitat in the area that is now the EW has been either filled or dredged and channelized. There are no remaining tidal marsh or expansive mudflat areas within the EW.

The aquatic habitats in the EW include the water column and intertidal and subtidal substrates (typically mud, sand, gravel, cobble, or riprap). The habitat within EW is predominately deep water habitat with relatively little shallow subtidal and intertidal habitat, which is found primarily in the Junction/Sill reach, within Slip 27, and south of Slip 36 (approximately 6 acres have been identified as intertidal areas).

Shoreline armoring is present throughout the upper intertidal zone, but a few isolated areas of sloping mud and sand flats and gravel/cobble exist in the lower intertidal zone. Most of the intertidal sediment areas are along the eastern shoreline of the EW. Along the western shore, intertidal sediment is limited to small areas under the bridges. Gravel and cobble are the dominant matrices in the exposed intertidal areas. In addition, overwater structures, which are common throughout the EW, shade shallow water and intertidal habitats and inhibit the growth of plant communities (Battelle et al. 2001).

Areas within the EW that have been restored or may be restored in the future to enhance habitat conditions are listed below:

- In the Junction Reach, habitat restoration was conducted in 1989 with the creation of a shallow bench along the eastern shoreline at T-104, which was constructed of clean fine-grained substrate and provides valuable shallow water habitat for juvenile migratory fish and intertidal areas for clams.
- In the Sill Reach, habitat restoration is anticipated to be conducted by Bluefield Holdings, Inc. for the west side of the EW under the West Seattle Bridge, which would provide off-channel mudflat and marsh habitat, along with riparian vegetation. The restoration project would also involve removal of debris and creosote structures from the shoreline areas. The restoration is subject to Natural Resource Damage Trustee approval, EPA coordination, and obtaining permitting from federal, state, and City agencies. Construction timing is unknown.
- Just north of the Spokane Street Bridge, a mound of fill stabilized by rock was placed specifically for habitat restoration purposes. This mound provides shallow water and intertidal habitat.
- The bank along the southern part of Slip 27 has been replanted in an effort to restore natural habitat conditions to this area. The restoration extends from the top of bank (18.5 feet MLLW) down to 12 feet MLLW.

- Jack Perry Park is a 1.1-acre park located north of T-30 and south of the USCG facility. It provides 120 feet of intertidal area and shoreline access for public recreational activities and, as such, provides an area for potential future habitat enhancements.

2.9.4.2 Biological Communities

Dredging and development over the past 100 years have substantially altered nearshore environments in Elliott Bay and the Duwamish River estuary. Currently there is no natural shoreline in the EW. The aquatic habitats found in the EW are intertidal and subtidal, and water column habitats. Numerous infaunal and epibenthic invertebrate species inhabit the intertidal and subtidal substrates of the EW. Larger invertebrates also inhabit the EW, including crabs (Dungeness crabs [*Cancer magister*], red rock crabs [*Cancer productus*], graceful crabs [*Cancer gracilis*]), arthropods, and echinoderms.

Clam surveys were conducted at 11 intertidal areas (Windward 2010b); five of these areas were located in the southern narrow portion of the EW, three were located in and near Slip 27, and three were located along the shoreline south of Slip 36 (Figure 2-11). Nine of these intertidal areas contained suitable habitat for clams in the EW. During this survey, Macoma clams (*Macoma* spp.) were the most frequently observed species, followed by Japanese littleneck clams (*Venerupis philippinarum*) and butter clams (*Saxidomus gigantean*). Cockles (*Clinocardium nuttali*) and Eastern soft-shell clams (*Mya arenaria*) were observed only in the southern-most portion of the EW, under the bridges and along the restoration bench, respectively. Mussels were present wherever suitable substrate was present, primarily on pilings and sheetpile walls, based on a July 2008 survey. Geoducks are also present in deeper water in the northern part of the EW (Windward 2010c).

Diverse populations of fish, including 42 anadromous and resident fish species, also reside in or use the EW as a migration corridor. Salmon use the Duwamish River for rearing of juveniles and as a migration corridor for adults and juveniles. Adult salmon found in the LDW and EW spawn mainly in the middle reaches of the Green River and its tributaries (Grette and Salo 1986). Five species of juvenile salmon (Chinook [*Oncorhynchus tshawytscha*], chum [*Oncorhynchus keta*], coho [*Oncorhynchus kisutch*], pink

[*Oncorhynchus gorbuscha*], and steelhead [*Oncorhynchus mykiss*]) have been documented in the EW. Juvenile chum and Chinook salmon were the most abundant salmonid species captured in Slip 27 (Taylor Associates 2004; Shannon 2006; Windward 2010d). Sockeye salmon have been found upstream in the LDW (Kerwin and Nelson 2000). Juvenile salmon are expected to primarily feed in suitable nearshore habitats.

Of non-salmonid fish, English sole (*Parophrys vetulus*), Pacific herring (*Clupea pallasi*), Pacific staghorn sculpin(*Leptocottus armatus*), Pacific tomcod (*Microgadus proximus*), rock sole (*Lepidopsetta bilineata*), sand sole (*Psettichthys melanostictus*), shiner surfperch (*Cymatogaster aggregate*), sanddab species *(Citharichthys spp*), starry flounder (*Platichthys stellatus*), surf smelt (*Hypomesus pretiosus*), and three-spine stickleback (*Gasterosteus aculeatus*) are at least seasonally abundant in the EW.

There is very little information on bird and mammal populations in the vicinity of the EW; however, the relatively large home ranges associated with many bird and mammal species make the LDW data relevant to the EW. The LDW habitats support a diversity of wildlife species. Previous studies have reported 87 species of birds, 3 species of marine mammals, and 3 species of aquatic-dependent terrestrial mammals that use the LDW at least part of the year to feed, rest, or reproduce (Windward 2007a).

Sixteen aquatic and aquatic-dependent species reported in the vicinity of Elliott Bay area are listed under either the Endangered Species Act or by the Washington Department of Fish and Wildlife as candidate species, threatened species, endangered species, or species of concern. Of these species, Chinook salmon, coho salmon, steelhead salmon, brown rockfish (*Sebastes auriculatus*), bald eagle (*Haliaeetus leucocephalus*), western grebe (*Aechmophorus occidentalis*), and Pacific herring are commonly observed in the EW.

2.10 EW Baseline Dataset

Environmental investigations conducted within the EW, primarily in support of the SRI and dredging activities, have included the collection of surface sediment, subsurface sediment, fish, shellfish, benthic invertebrate tissue, surface water, and porewater samples for chemical analysis. This baseline dataset was used to support analyses in the SRI, including the ERA, the HHRA, the nature and extent evaluation, and the development of sediment RBTCs for human health and ecological receptors of concern. Eight surface sediment samples collected from Slip 36 within the EW in November 2014 (Amec Foster Wheeler 2015) were added to the SRI baseline dataset for the FS evaluation.[9] Additional data are also included in Appendix J for the purposes of recontamination evaluation (e.g., EW SD and CSO solids source control datasets, atmospheric deposition, and groundwater) and comparison to background. For the FS, the sediment data needed to support the design of remedial alternatives are the primary data used. The various components of data that make up the FS dataset are detailed below.

2.10.1 Surface Sediment

The surface sediment baseline dataset consists of 334 individual surface sediment samples from the EW SRI dataset, plus an additional 8 surface sediment samples collected in 2014 (342 total). The majority of the surface samples were collected for the purpose of site-wide characterization in 1996, 2002, and 2010; the dataset is well distributed spatially and representative of the site as a whole.

The intertidal sediment has been less frequently sampled, in part because there are few intertidal areas in EW. Multi-increment sampling (MIS) samples were collected to characterize the intertidal sediment for the risk assessments. The MIS samples consisted of four composite samples that were created from a total of 138 discrete surface sediment samples collected throughout the intertidal areas of the EW, each composite sample was created by combining approximately 30 unique sediment samples collected throughout the EW intertidal area. However, the MIS dataset is not being used in the FS since the four sample areas (encompassing all intertidal areas with clams) were composited specifically to evaluate HHRA direct contact clamming exposure scenarios, and not for remedial alternative evaluation.

In addition to the four intertidal MIS composite samples, polycyclic aromatic hydrocarbons (PAHs) were also analyzed as 15 different intertidal area composite samples (each of these

[9] These locations were sampled after the risk assessments (Windward 2012a, 2012b), initial EW FS modeling work, and source and pathway characterization data cutoff of August 2010. However, they are included in the statistical summaries of contamination in Section 2 and have been used to expand the remediation footprint in Section 6.

areas was part of an MIS sample composite area) created to characterize carcinogenic polycyclic aromatic hydrocarbons (cPAHs) in each intertidal sampling area (see Section 4.2.6.1 of the SRI; Windward and Anchor QEA 2014). cPAHs were further evaluated in the 15 intertidal composite samples because one of the three area-wide intertidal MIS replicate samples contained substantially higher concentrations of cPAHs than the other two area-wide MIS samples and had higher cPAH concentrations than the public access intertidal MIS composite sediment sample. This variance suggested that one or more sediment grab samples within the MIS composite contained elevated cPAH concentrations relative to the grab samples that went into the other replicate MIS samples. To identify the area with elevated cPAH concentrations, sediment volume from discrete sampling points used to create the MIS samples were combined by geographic subarea to create 15 intertidal composites to represent the nature and extent of cPAH contamination in the beach areas (see SRI Map 4-27).

Subtidal composite samples were created for 13 areas for the analysis of dioxins/furans and PCB congeners (see Figure 2-18). The intertidal area PAH samples and subtidal composites dioxin/furan samples, along with surface sediment grab samples, are used in this FS.

2.10.2 Subsurface Sediment

The baseline dataset includes 346 subsurface samples from 146 cores. A total of 214 samples (from 67 cores) were collected during site-wide investigations, including the SRI subsurface sediment sampling in 2010. The remaining 132 samples (from 79 cores) were collected to characterize sediment quality in potential dredging areas that were ultimately not dredged. Because the majority of the data were collected for the purpose of site-wide characterization, the dataset is well distributed spatially and representative of the site as a whole.

2.10.3 Phase 1 Dredge Area

The Phase 1 dredge area within the EW (see Figure 2-21), has four sets of surface sediment (0 to 10 cm) chemistry data (collected in 2005, 2006, 2007, and 2008). The Phase 1 dredge area was dredged between 2004 and 2005 and was then covered with a 1-foot-thick layer of sand cover material (March 1 to 15, 2005) and subsequently monitored annually for 3 years.

After initial dredging was completed, post-dredge samples were collected in January 2005 to determine if additional dredging was needed in locations where sediment concentrations were not substantially reduced. After completion of additional dredging in select areas, pre-sand placement (i.e., post-dredge) sediment samples were collected in February 2005 and analyzed for the analytes that exceeded sediment quality standards (SQS) in the January 2005 post-dredge surface (metals, semivolatile organic compounds [SVOCs], and PCBs), so the concentrations of analytes that exceeded the SQS in sediment remaining in place would be known.

A sand layer was then placed to meet Ecology's anti-degradation policy requirements and to not leave a contaminated surface exposed. The thickness measured after placement ranged from 6 inches to more than 1 foot and averaged 10 inches (Anchor and Windward 2005), and since that time several years of new material has deposited. After placement of the sand, subsequent surface sediment quality monitoring was conducted for 3 years (2006 to 2008) to evaluate the integrity of the sand layer and monitor potential recontamination.

Consistent with the SRI, the FS uses data from the pre-sand placement (February 2005)[10] and subsequent post-sand placement monitoring events (2006 to 2008)[11] to define areas requiring remediation. These dredging and sand placement activities were used to inform technology application assumptions that would be employed in the EW (Sections 7 and 8). In addition, observations from these monitoring events were used to inform methods for estimating post-cover concentrations used in modeling (Appendix B, Part 3A).

2.10.4 Other Datasets Used in the FS

Several other datasets were used to characterize the contaminant concentrations associated with upstream inputs from LDW lateral and sediment bed concentrations and Green River sources. The EW uses the same datasets as the LDW to characterize the contaminant concentrations associated with LDW lateral inputs (e.g., SDs and CSOs) and Green River

[10] The pre-sand placement sediment data from 2005 are provided in the SRI (Windward and Anchor QEA 2014) and are treated as shallow subsurface sediment because the sediments are currently covered by sand cover material with a minimum thickness of 6 inches.

[11] Only most recent post-sand placement monitoring results were used for co-located samples.

upstream inputs, except one new core collected in 2010 from the Turning Basin for dredged material characterization was added to the dataset (see Section 7 of the SRI; Windward and Anchor QEA 2014). Datasets used to characterize Green River inputs include cores collected in the most upstream portion of the LDW navigation channel and upper turning basin, surface sediment samples and solids from centrifuged water samples collected upstream of the LDW (many collected by Ecology), and whole-water samples collected by the County upstream of the LDW. All of these datasets are discussed in Appendix C, Part 3 of the LDW FS (AECOM 2012). The LDW sediment bed concentrations were based on LDW surface sediment summaries presented in the LDW FS (AECOM 2012).

Natural background concentrations of certain contaminants were estimated for use in developing PRGs (Section 4.3.3) and the recontamination evaluation (Section 5). Natural background concentrations were estimated from a statistical evaluation of surface sediment data collected from non-urban areas in Puget Sound. The Dredged Material Management Program (DMMP) agencies collected these data in 2008 during the Puget Sound sediment Ocean Survey Vessel (OSV) *Bold* Summer 2008 Survey (OSV *Bold* Survey; DMMP 2009). These data are discussed in Section 4 for the development of PRGs. Appendix B estimates sediment concentrations entering the EW using upstream contributions (Green River and LDW) and EW lateral inputs. The upstream contributions and lateral input data are further evaluated in Section 5 and are used to estimate net incoming solids concentrations for the purposes of the recontamination evaluation. In addition, the upstream contributions and lateral inputs are used in Appendix A to evaluate the technical possibility of achieving natural background-based PRGs.

2.10.5 Tissue

Tissue samples of many different fish and invertebrate species have been collected and analyzed. Tissue data included samples of English sole, shiner surfperch, brown rockfish, juvenile Chinook salmon, red rock and Dungeness crabs, intertidal clams (i.e., butter, little neck, cockles, and Eastern soft-shell), mussels, geoducks, shrimp, and small benthic invertebrates that live in or on the sediment, such as amphipods and marine worms. These species were selected because they were either known or assumed to be representative of species that could be consumed by people, fish, or aquatic-dependent wildlife within the EW or they were identified as important ecological receptors of concern. Their tissues were analyzed for a wide variety of contaminants. Tissue data were used to evaluate risks to human health and ecological receptors in the HHRA (Windward 2012b) and ERA (Windward 2012a), respectively. The PRGs in this FS are developed to reduce the risks to people who consume seafood from the waterway or come into contact with EW sediments and water and ecological receptors that live or forage within the waterway.

2.10.6 Water

PCB surface water data were used in food web modeling, which was used in developing RBTCs between tissues and sediments. Other surface water data were not used in development of RBTCs. Surface water data can be used during evaluation of site conditions compared to state water quality standards, an ARAR for the sediment cleanup.

Contaminant concentrations in surface water and porewater were also summarized in the SRI (Windward and Anchor QEA 2014). A large number of surface water grab samples were collected along a transect in the EW (at Station 4950) by King County between October 1996 and June 1997 and analyzed for conventional parameters, metals, and SVOCs. Surface water sampling was also conducted in 2008 and 2009 as part of the SRI. Samples were collected from five locations throughout the EW during the wet season, the dry season, and a large storm event. These samples were analyzed for conventional parameters, metals, SVOCs, and PCB congeners. SVOCs were not detected in the King County samples. Improved sensitivity in the analyses resulted in higher detection frequencies for SVOCs in the SRI dataset.

Porewater data were collected from subtidal surface and subsurface sediments for the analysis of tributyltin (TBT) primarily in samples collected for dredge material characterization and post-dredge monitoring studies. TBT was detected in 83 out of 99 samples. In addition, 13 porewater samples were collected from two intertidal areas for the analysis of volatile organic compounds (VOCs). Naphthalene was detected in two samples, benzene was detected in two samples, and cis-1,2-dichloroethene was detected in one sample.

2.11 Conceptual Site Model

2.11.1 Physical Conceptual Site Model

The physical CSM focuses on the important processes that affect hydrodynamic and sediment transport processes in the EW. Information used to develop the physical CSM included site-specific empirical data and output from hydrodynamic, sediment deposition, and propeller wash (propwash) modeling, as presented in the STER (Anchor QEA and Coast & Harbor Engineering 2012) and summarized in the SRI (Windward and Anchor QEA 2014). Empirical data collected as part of this work include tidal elevations from Elliott Bay and the EW, flow data from the Green River, velocity and salinity profile measurements south and north of the Spokane Street Corridor and within the main body of the EW, sedimentation data from the EW, and in situ measurements of critical shear stress in the EW. Model output included predictions of current velocities, salinities, and suspended solids for average and high-flow events within the EW (hydrodynamic model), predictions of annual average initial deposition patterns from lateral sources within the EW (particle tracking model [PTM]), and near-bottom current velocities due to vessel operations (from propwash) within the EW. Figure 2-12 presents a graphical summary of the sediment transport processes within the EW.

Hydrodynamic circulation in the EW is controlled by tidal exchange with Elliott Bay to the north and freshwater inflow from the Green River (through the LDW). Stormwater and CSO inflows from the directly contributing drainage basins have a negligible influence on large-scale circulation in the EW. Water circulation in the EW can be generally described as two-layer flow, with saltwater extending from Elliott Bay upstream through the EW and into the LDW underneath a thin layer of fresher water flowing from the Green/Duwamish River system (Figure 2-12). In general, as upstream inflow increases, predicted surface velocities within the EW increase. Average surface velocities range from 20 to 25 centimeters per second (cm/s), and maximum surface velocities range from 90 to 95 cm/s (2- to 100-year flows, respectively). Average and maximum predicted surface velocities at mean annual flow are 10 and 70 cm/s, respectively. Predicted average near-bed velocities are relatively constant over the range of flows from mean annual to the 100-year upstream flow at 5 cm/s. Maximum near-bed velocities increase with increasing upstream flow; from 18 to 28 cm/s for mean annual and 100-year flows, respectively.

The vertical gradient in salinity in the EW is directly related to upstream flow into the EW, with the range in salinity between surface water and bottom water increasing with increasing upstream flow. However, the majority of the water column remains saline even under the 100-year flow conditions (as predicted by the hydrodynamic model). The split in flow between the EW and WW is predicted from modeling to be about equal during normal flow events (annual average) but approximately 30%:70% (EW:WW) during 2-year flows and higher events. The split in flow was validated over a range of tidal conditions during a higher flow event (4,000 cubic feet per second [cfs]) using Acoustic Doppler Current Profiler (ADCP) transect data collected within the EW as part of the sediment transport evaluation (STE).

Sediment sources to the EW include the upstream sources (Green River, LDW bed and bank sediments, and LDW lateral load sediments), downstream sources (Elliott Bay), and local sources (lateral sources that drain directly to the EW). An evaluation of 18 geochronology cores recovered within the EW suggests that the majority of the Shallow Main Body Reach (between Stations 5000 and 6800) and the interior of Slip 27 (Figure 2-1) are net depositional. Net sedimentation rates for these areas range from 0.2 to greater than 2.0 centimeters per year (cm/yr). The Deep Main Body Reach (Stations 0 to 5000), including the mouth of Slip 36, appears to be net depositional but influenced by episodic erosion events due to propwash from vessel operations. Prop wash mixing events may also result in episodic scour of naturally deposited sediments in some areas of the Deep Main Body Reach, and therefore, long-term net sedimentation is functionally zero. Consistent with patterns of changes in bathymetric elevations within the waterway, some of the sediment mobilized during vessel scour events is deposited in adjacent areas within the EW. The extent of areas with functional zero net sedimentation was not quantified. Geochronology cores were not retrieved in the Sill and Junction Reaches due to consolidated sand and gravel surface sediments at proposed sampling locations in these areas. Therefore, net sedimentation rates could not be quantified for the Sill or Junction Reaches. This result suggests that the Sill and Junction Reaches may not be net depositional in some areas. The extent of areas with no net deposition was not quantified.

Results of the sediment transport modeling completed for the LDW (QEA 2008) and results of the PTM for initial deposition of lateral sources within the EW completed for this FS suggest that 99% of the sediment load entering the EW is from the Green River, approximately 0.7% is from the LDW (bed sediments and lateral loads), and less than 0.3% is from lateral loads within the EW itself (Anchor QEA and Coast & Harbor Engineering 2012). Results from the LDW sediment transport model (QEA 2008) suggest that essentially 100% of the incoming upstream load to the EW from the Green River and LDW (bed sediments and lateral loads) consist of silts and clays. Sediment load into the EW from Elliott Bay is assumed to be negligible compared to the other sources. A comparison of predicted estimates of sediment loads and average net sedimentation rates in the EW (measured from geochronology cores) indicates that 25% to 60% of the incoming sediment load is estimated to deposit in the EW (capture efficiency) and 40% to 75% of the incoming load is estimated to leave the EW. Initial mass deposition patterns within the EW from local lateral sources (evaluated through PTM) show the majority of initial deposition occurs close to the outfall locations, with relatively little deposition (less than 0.2 cm/yr) compared to the average net sedimentation rates in the EW (Figure 2-14). Contaminants associated with various sediment sources are presented in Section 5.

As presented in the STER (Anchor QEA and Coast & Harbor Engineering 2012), riverine and tidal currents in the EW are not expected to cause significant erosion of in situ bed sediments, as the maximum predicted bed shear stress during a 100-year high-flow event modeled to be less than the mean critical shear stress[12] of the bed sediments (estimated from site-specific SEDflume data). Modeled bed shear stress due to large vessel operations (e.g., propwash) in portions of the Deep Main Body Reach (north of Station 4200) is significantly greater than bed shear stress due to natural forces and is regularly above the critical shear stress for bedded sediments. Consequently, these areas are likely subject to episodic erosion and re-suspension of bed sediments due to propwash. The remainder of the Deep Main Body Reach (between Stations 4200 and 4900), the Shallow Main Body Reach, and the Junction Reach are also subject to impacts from vessel operations; however, the vessels that operate in these areas are smaller in size and operate less frequently than in the Deep Main Body Reach (north of Station 4200). Therefore, these areas may be subject to occasional erosion or re-suspension of surface sediments due to propwash.

[12] In the STER (Anchor QEA and Coast & Harbor Engineering 2012) and SRI (Windward and Anchor QEA 2014), critical shear stress is defined as a property of the in situ bed sediments. It represents the value of shear stress (applied to that bed due to current velocities) at which the bed sediment would begin to mobilize (e.g., erode).

Information on vessel types and typical and extreme vessel operations during berthing and navigation with the EW were compiled in the STER (Anchor QEA and Coast & Harbor Engineering 2012) and SRI (Windward and Anchor QEA 2014). This information was used to develop operational areas within the EW where potential vessel operations were similar. These operational areas and the propwash evaluation are discussed in Section 5.

2.11.2 Chemical CSM (Nature and Extent of Contamination in Sediment)

Four risk driver COCs were identified in the HHRA for the EW based on risks associated with seafood consumption or direct sediment contact: total PCBs, arsenic, cPAHs, and dioxins/furans (see Section 3.2). Total PCBs and TBT were also identified in the ERA as risk driver COCs for fish and benthic invertebrates, respectively (see Section 3.1). In addition, 29 chemicals were identified as COCs for benthic invertebrates because detected concentrations of these 29 chemicals exceeded the SQS of the Washington State SMS at one or more locations. Total PCB concentrations and mercury concentrations in surface sediment exceeded the SQS at the greatest number of locations.

Tables 2-1 and 2-2 summarize minimum and maximum detections, average concentrations, and detection frequencies of human health and benthic risk drivers, respectively. Figures provided in this section and in subsequent sections of the FS use Thiessen polygons[13] to spatially represent results from specific point locations.[14] This method was selected rather than other interpolation methods due to the high density of samples collected from the EW, the relative lack of bias in sample locations, and for consistency with comparisons of point concentrations to SMS criteria and other point-based RALs. The distributions of risk driver COCs in sediment are discussed below and shown in Figures 2-15 through 2-20. Additional details on the nature and extent of contamination is presented in the SRI (Windward and Anchor QEA 2014); only summary level information is presented in the FS.

[13] All methods of estimation by interpolation have uncertainty, including interpolation by Thiessen polygon.

[14] Dioxins and furan TEQ and TBT concentrations are not represented on figures as Thiessen polygons, but as individual points due the smaller size of these datasets. During remedial design, additional samples may be collected and tested where dioxin and furan information is limited.

2.11.2.1 Surface Sediment Chemistry

Human Health Risk Drivers

Table 2-1 summarizes the concentrations in the EW for the four human health risk drivers: total PCB, cPAH, arsenic, and dioxin/furan toxic equivalent (TEQ). These results are presented in dry weight for consistency with the RBTCs developed in the SRI (Windward and Anchor QEA 2014). PCBs are widely distributed in surface sediment throughout the EW. Total PCBs were detected in 95% of the 248 surface sediment samples in which they were analyzed, at concentrations ranging from 6 to 8,400 µg/kg dw, with a mean concentration of 490 µg/kg dw and a SWAC of 460 µg/kg dw.

Table 2-1
Statistical Summaries for Human Health Risk Driver COCs in Surface Sediment

Contaminant	Unit	Detection Frequency	Concentration				SWAC
			Mean	Median	95th Percentile	Maximum	
Surface							
Total PCBs[a]	µg/kg dw	235/248	490	290	1,600	8,400	460
cPAHs[b]	µg TEQ/kg dw	15/15[c]	1,900	230	nc	17,000	680
		241/248	1,600	250	3,500	68,000	
Arsenic[d]	mg/kg dw	170/239	11	6.7	21	250	9.0
Dioxins/ furans[e]	ng TEQ/kg dw	13/13[f]	16	16	nc	31	nc
		19/19[g]	32	38	52	71	
MIS composite samples[h]							
Total PCBs[a]	µg/kg dw	3/3[i]	970	770	nc	1,590	nc
		1/1[j]	nc	nc	nc	370	
cPAHs[b]	µg TEQ/kg dw	3/3[i]	1,000	780	nc	1,900	nc
		1/1[j]	nc	nc	nc	390	
Arsenic[d]	mg/kg dw	3/3[i]	10	9.1	nc	13.3	nc
		1/1[j]	nc	nc	nc	7.7	
Dioxins/ furans[e]	ng TEQ/kg dw	3/3[i]	12.1	13.2	nc	13.8	nc
		1/1[j]	nc	nc	nc	8.52	
Subsurface							
Total PCBs[a]	µg/kg dw	207/290	1,500	275	4,300	17,600	nc
cPAHs[b]	µg TEQ/kg dw	218/269	1,000	250	3,600	23,000	nc
Arsenic[d]	mg/kg dw	250/255	10	9	29	96	nc
Dioxins/ furans[e]	ng TEQ/kg dw	16/16	17.2	2.70	78.0	184	nc

Notes:

a. Total PCBs represent the sum of the detected concentrations of the individual Aroclors. If none of the individual Aroclors were detected in a given sample, the non-detect value represents the highest reporting limit.
b. Total cPAH TEQs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds. PEF values (California EPA 2005; Ecology 2001) are based on the individual PAH component's relative toxicity to benzo(a)pyrene. By using the PEFs, the toxicity of the various cPAH compounds can be expressed as a single number, the TEQ. If an individual PAH compound was not detected, the PEF for that compound was multiplied by one-half the RL for that compound.
c. Intertidal composite samples.
d. Summary statistics were calculated assuming one-half the reporting limit for non-detect results.
e. Dioxin/furan TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006). The TEF expresses the toxicity of dioxins/furans relative to the most toxic form of dioxin (2,3,7,8-TCDD). By using the TEFs, the toxicity of the various dioxin/furan congeners can be expressed as a single number, the TEQ. Dioxin/furan TEQs were calculated for each sample by summing the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener. In cases where the congener result was K-flagged or EMPC-flagged, the TEF for that congener was multiplied by one-half the reported value for that congener.
f. Subtidal surface composite samples collected in 13 subareas of the waterway.
g. Sediment grab samples selected for dioxin/furan analysis.
h. Intertidal composite samples collected using multi-increment sampling (MIS) technique.
i. Area-wide intertidal MIS composite.
j. Public access intertidal MIS composite.

µg – microgram
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
EMPC – estimated maximum possible concentration
kg – kilogram
MIS – multi-increment sampling
nc – not calculated
ng – nanogram
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
RL – reporting limit
SWAC – spatially-weighted average concentration
TEF – toxic equivalency factor
TEQ – toxic equivalent

At least one cPAH compound was detected in 97% of the 248 surface sediment grab samples, with concentrations ranging from 15 to 68,000 µg TEQ/kg dw, with a mean concentration of 1,600 µg TEQ/kg dw and a SWAC of 680 µg TEQ/kg dw (Table 2-1). In addition to the surface sediment grab samples, cPAHs were measured in four intertidal MIS composite samples (encompassing all intertidal areas with clams) and 15 intertidal composite samples (each of these were part of the MIS sampling area) created to characterize cPAHs in each intertidal sampling area (Figures 2-16a through 2-16c). cPAHs were detected in all 15 of the surface sediment intertidal composite samples, with concentrations ranging from 18 to 17,000 µg TEQ/kg dw (Table 2-1).

Arsenic was detected in 71% of the 239 surface sediment grab samples with a range of concentrations from 2.3 to 250 mg/kg dw with a mean concentration of 11.0, a 95th percentile of 21 mg/kg dw, and a SWAC of 9.0 mg/kg dw (Table 2-1 and Figures 2-17a through 2-17c).

Dioxins/furans were measured in subtidal composite sediment samples created for 13 subareas throughout the waterway and in four intertidal MIS composite sediment samples. Dioxins/furans were detected in all 13 subtidal composite samples with TEQ concentrations ranging from 4.0 to 31 nanograms (ng) TEQ/kg dw, and in all four intertidal MIS composite samples with concentrations ranging from 9.2 to 13.8 ng TEQ/kg dw. In addition, 19 individual surface sediment grab samples were analyzed for dioxins/furans. Dioxins/furans were detected in all 19 grab samples with TEQ concentrations ranging from 2.8 to 71 ng TEQ/kg dw (Table 2-1 and Figures 2-18a through 2-18c).

Benthic Risk Drivers

Table 2-2 presents a summary of chemicals detected in surface sediment samples relative to numerical chemical SMS criteria[15] to evaluate potential risk to benthic organisms. The SMS criteria uses two values: the SQS (WAC 173-204-320) and the cleanup screening level (CSL) (WAC 173-204-562). The SQS criteria represent numerical chemical concentrations below which sediment is designated as having no adverse effect on biological resources. The CSL criteria represent chemical concentrations at which minor adverse effects on biological resources are expected to occur. At chemical concentrations above the SQS but below the CSL, sediment is designated as having the potential for minor adverse effect on biological resources. To facilitate the evaluation of SMS exceedances, Table 2-2 presents an exceedance factor, which is the ratio of the maximum detected concentration of a chemical to either the SQS or CSL criteria.

In surface sediment, 175 locations (out of 251) had one or more exceedance of the chemical SQS. Detected total PCBs most frequently (65%) exceeded its SQS or CSL criterion, followed

[15] Many of the SMS criteria are in units normalized to the organic carbon (OC) content in the sediment sample (e.g., mg/kg OC) because the carbon content can affect the bioavailability or toxicity of nonpolar or nonionizable organic chemicals to benthic organisms. OC-normalization is not considered to be appropriate for TOC concentrations ≤ 0.5% or ≥ 4.0%. In these cases, dry weight chemical concentrations were compared with the lowest apparent effects threshold (LAET), which is functionally equivalent to the SQS, or the second lowest AET (2LAET), which is functionally equivalent to the CSL.

by mercury (21%) and 1,4-dichlorobenzene (13%). All other detected chemicals exceeded their respective SQS or CSL criteria in less than 10% of the samples.

Twenty-four contaminants exceeded their respective CSL in at least one sample, with total PCBs being the most frequently detected above its CSL criterion (23 of 248 locations, or 9.3%) followed by acenaphthene (13 of 248 locations, or 5.2%) and mercury (10 of 247 locations, or 4.0%); all other contaminants were detected above their respective CSL criterion in less than 4% of the samples.

The SMS also include biological criteria (WAC 173-204-315) based on sediment toxicity tests and benthic infauna abundance. Because apparent effects thresholds (AETs), which form the basis for the SMS chemical criteria, are based on sediment samples with a mixture of chemicals from various locations in Puget Sound and the exceedance of the SMS chemical criteria is not always an accurate predictor of adverse effects, the regulations state that site-specific biological tests (sediment toxicity tests and the assessment of benthic infauna abundances) may be conducted to provide confirmation that site-specific chemistry data indicate a hazard to benthic invertebrate communities. According to the state regulations, the tested sediments are designated as exceeding the SQS if the SQS biological criteria are exceeded for any one of the three toxicity tests conducted for a sampling location. Likewise, sediments are designated as exceeding the CSL if the CSL biological criteria are exceeded for any one of the three toxicity tests, or if the SQS biological effects criteria are exceeded in any two of the three toxicity tests conducted for a sampling location (WAC 173-204-420(3)). The SQS and CSL designations based on biological criteria override the SQS and CSL designations based on chemistry results. For example, if a location has a chemical CSL exceedance but is tested and found not to exceed the biological SQS criterion, it is not categorized as an SMS exceedance.

Table 2-2
Statistical Summaries for Benthic Risk Driver COCs in Surface Sediment

Chemical	Detection Frequency		Frequency of Detected Concentrations > SQS and ≤ CSL			Maximum Detected SQS EF	Frequency of Detected Concentrations > CSL			Maximum Detected CSL EF
	No. of Samples[a]	%	No. of Samples[b]	%	No. Non-detected with RL > SQS and ≤ CSL		No. of Samples[c]	%	No. Non-detected with RL > CSL	
Metals										
Arsenic	170/239	71	0/239	0.0	0	4.4	3/239	1.3	0	2.7
Cadmium	163/239	68	1/239	0.4	0	1.3	1/239	0.4	0	1.0
Mercury	241/247	98	41/247	17	0	2.6	10/247	4.0	0	1.8
Zinc	239/239	100	4/239	1.7	0	3.2	2/239	0.8	0	1.4
PAHs										
2-Methylnaphthalene	95/248	38	0/248	0.0	0	2.2	3/248	1.2	0	1.3
Acenaphthene	134/248	54	11/248	4.4	0	53.1	13/248	5.2	0	38.0
Anthracene	217/248	88	5/248	2.0	0	19.8	2/248	0.8	0	19.8
Benzo(a)anthracene	234/248	94	7/248	2.8	0	31.5	7/248	2.8	0	25.6
Benzo(a)pyrene	233/248	94	7/248	2.8	0	27.5	8/248	3.2	0	27.5
Total benzofluoranthenes[e]	236/248	95	7/248	2.8	0	21.3	8/248	3.2	0	18.9
Chrysene	238/248	96	9/248	3.6	0	32.1	3/248	1.2	0	16.1
Dibenzofuran	115/248	46	9/248	3.6	0	17.8	6/248	2.4	0	6.3
Fluoranthene	241/248	97	15/248	6.0	0	46.5	7/248	2.8	0	31.6
Fluorene	152/248	61	10/248	4.0	0	21.1	9/248	3.6	0	16.1
Phenanthrene	238/248	96	14/248	5.6	0	37.3	9/248	3.6	0	37.3
Pyrene	243/248	98	2/248	0.8	0	31.9	5/248	2.0	0	25.2
Total HPAHs[g]	245/248	99	10/248	4.0	0	34.1	7/248	2.8	0	24.1

Table 2-2

Statistical Summaries for Benthic Risk Driver COCs in Surface Sediment

Chemical	Detection Frequency		Frequency of Detected Concentrations > SQS and ≤ CSL			Maximum Detected SQS EF	Frequency of Detected Concentrations > CSL			Maximum Detected CSL EF
	No. of Samples[a]	%	No. of Samples[b]	%	No. Non-detected with RL > SQS and ≤ CSL		No. of Samples[c]	%	No. Non-detected with RL > CSL	
Total LPAHs[h]	238/248	96	6/248	2.4	0	20.0	9/248	3.6	0	20.0
Phthalates										
BEHP	215/239	90	4/239	1.7	1	40.0	5/239	2.1	1	24.0
Benzylbutyl phthalate	109/239	46	16/239	6.7	6	3.8	0/239	0.0	0	0.3
Di-n-butyl phthalate	33/239	14	0/239	0.0	0	12.0	1/239	0.4	0	1.5
Other SVOCs										
1,4-Dichlorobenzene	153/239	64	21/239	8.8	2	350.0	9/239	3.8	0	120.0
2,4-Dimethylphenol	19/239	8	0/239	0.0	0	3.8	9/239	3.8	39	3.8
n-Nitrosodiphenylamine	2/239	1	0/239	0.0	0	6.4	3/239	1.3	2	4.5
PCBs										
Total PCBs	235/248	95	137/248	55	0	70.0	23/248	9.3	0	13.0
TBTs										
TBT[k]	68/75	91	11/75	15	0	50.0	NA	NA	NA	NA

Notes:

a. Represents the number of detects per total number of samples.

b. Represents the number of detects > SQS and ≤ CSL per total number of samples. If any individual sample had a TOC content > 4% or < 0.5% and the dry-weight concentration was > LAET and ≤ 2LAET, the concentration was considered to be > SQS and ≤ CSL.

c. Represents the number of detects > CSL per the total number of samples. If any individual location had a TOC content > 4% or < 0.5% and the dry-weight concentration was > 2LAET, the concentration was considered to be > CSL.

d. One of these six samples could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.

e. Total benzofluoranthenes were calculated as the sum of benzo(b)fluoranthene and benzo(k)fluoranthene.
f. One of these three samples could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.
g. Total HPAHs were calculated as the sum of benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.
h. Total LPAHs were calculated as the sum of acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.
i. This sample could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.
j. Two of these twenty-three samples could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.
k. TBT does not have SMS criteria; however, the ecological risk assessment (Windward 2012a) calculated a RBTC of 7.5 mg/kg OC for benthic invertebrates. This RBTC value was used as a surrogate for the frequency of detected concentrations above the SQS column.

2LAET – second-lowest-apparent-effect threshold
BEHP – bis(2-ethylhexyl) phthalate
CSL – cleanup screening level
DDT – dichlorodiphenyltrichloroethane
DMMP – Dredged Material Management Program
dw – dry weight
EF – exceedance factor
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LAET – lowest-apparent-effect threshold
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligram per kilogram
NA – not applicable
OC – organic carbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RL – reporting limit
SRI – Supplemental Remedial Investigation
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SVOC – semivolatile organic compound
TBT – tributyltin
TOC – total organic carbon

Thiessen polygons were used to estimate the areal extent of potential benthic effects based on combined toxicity test results and surface sediment chemistry data. The maximum exceedance factor for individual SMS contaminants at each station was used to assign a status to that station's Thiessen polygon. Using the final SMS designation based on both sediment chemistry and toxicity test results, approximately 39% of the EW is designated as having no adverse effects to benthic community (all less than SQS), while approximately 23% are expected to have minor adverse effects (greater than or equal to CSL). Approximately 38% of the area was between the SQS and the CSL and is generally interpreted as having a potential for minor adverse effects on the benthic community.[16] Figures 2-20a through 2-20c show the final designation of each area, as represented by Thiessen polygon, according to SMS rules.

2.11.2.2 Subsurface Sediment Chemistry

In general, elevated subsurface contaminant concentrations were co-located with areas of elevated surface sediment concentrations. However, there were areas with subsurface sediment concentrations that exceeded the surface sediment concentrations. Slip 27 had generally higher subsurface sediment contaminant concentrations compared to the surface sediment concentrations and the shallow main body area had higher subsurface sediment concentrations of total PCBs and mercury relative to the surface sediment concentrations of these contaminants in that area. The analysis of vertical patterns of chemicals in subsurface sediment showed that elevated contaminant concentrations were mostly detected in deeper core intervals in areas that have not been dredged since the 1960s.

Overall, 95% of the cores collected from the EW during SRI sampling events had contaminant concentrations that were less than the SQS in the lowest interval of the core that was analyzed (Figures 2-20a through 2-20c). In the cores where the lower alluvium was analyzed (74% of the cores), only three locations had SQS exceedances in that zone (Figures 2-20a though 2-20c); however, the exceedances at depth at these locations were likely due to inclusion of transitional or contact layer material from the upper unit.

[16] As noted in Section 2.10.1, these values differ slightly from those presented in the EW SRI (Windward and Anchor QEA 2014) due to inclusion of Slip 36 data collected in 2014.

2.11.2.3 Sediment Chemistry in Phase 1 Dredge Area

The Phase 1 dredge area was sampled following completion of initial dredging (February 1, 2005), immediately after a second partial dredging (February 3 to 25, 2005), and following placement of a 1-foot-thick layer of sand cover material (March 1 to 15, 2005). Pre-sand placement sediment samples were collected following the removal of the additional foot of sediment and were analyzed for the analytes that exceeded the SMS in the post-dredge surface (metals, mercury, SVOCs, and PCBs). Mercury and total PCBs were the contaminants that exceeded the SQS and CSL in the greatest number of samples. The current surface, pre-sand placement surface, and subsurface chemistry relative to SMS exceedances are presented on Figure 2-21.

The current Phase 1 dredge area surface sediment dataset consists of post-sand placement data collected for recontamination monitoring in 2006, 2007, and 2008. The pre-sand placement surface sediment dataset is still valid, but considered subsurface sediment because the area is covered with at least 6 inches of sand cover material. Therefore, both the pre-sand and post-sand placement results are considered to establish the area of active remediation discussed in Section 6 and used together to represent sediment conditions in the clean sand placement areas of the Phase 1 dredge area on the figures presented in Section 6 to determine the extent of removal areas.

In the SRI (Windward and Anchor QEA 2014), the SQS exceedances for the current surface sediment data were compared with the surface sediment data prior to the placement of sand cover material (i.e., pre-sand placement sediment). The current surface sediment has fewer exceedances of the CSL than were seen in the pre-sand placement samples. The six locations with CSL exceedances in the current sediment surface are associated with surface sediment concentrations of total PCBs, 1,4-dichlorobenzene, and bis(2-ethylhexyl) phthalate (BEHP). These locations were not spatially associated with SMS exceedances for 1,4-dichlorobenzene or BEHP in the pre-sand placement sediment sampling. However, SMS exceedances for total PCBs were observed in pre-sand placement locations near two locations (EW-RM-34 and EW-RM-32) that exceed the SQS and CSL for total PCBs, respectively (Figure 2-21).

2.11.3 Sources and Pathways

After the physical and chemical settings are described, the third component of a CSM evaluates the source of the contaminants and the likely pathways by which these contaminants are transported into and within the EW.

2.11.3.1 Historical and Ongoing Chemical Contaminants and Sources

Today, many sources of historical origin, including direct discharges of municipal and industrial wastewater and spills, have been identified and controlled. These controls have been implemented by enhanced regulatory requirements, improved housekeeping practices, and technological advances. Further discussion of historical chemical contaminants is included in Section 9.2 of the SRI (Windward and Anchor QEA 2014).

2.11.3.2 Potential Ongoing Source Pathways

Potential sources of contaminants to media such as air, soil, groundwater, and surface water or to impervious surfaces may migrate to the EW through various pathways. The completeness of the pathways with respect to the transport of COCs and the evaluation of potential sources are summarized in this section and detailed in the SRI (Windward and Anchor QEA 2014). The potential ongoing sources and pathways to the EW include the following:

- Direct discharge into the EW (e.g., CSOs, stormwater, or sheetflow from properties immediately adjacent to the waterway)
- Groundwater discharge (including tidally influenced groundwater discharge)
- Bank erosion
- Atmospheric deposition
- Spills and/or leaks to the ground, surface water, or directly into the EW (may be a potential source or pathway)
- Abrasion and leaching of treated-wood structures
- Surface water inputs and sediment transport

As described in Sections 3 and 9 of the SRI (Windward and Anchor QEA 2014), direct discharges and upstream inputs are pathways of the predominant sources of sediment inputs to the EW; therefore, those two pathways for sources are integrated into the STE presented in Section 5 of this FS. Both the sediment transport processes and source inputs are incorporated into the assessment of sediment recontamination potential for the remedial alternatives in Section 9.

Sources and pathways to the EW are subject to ongoing regulatory, permitting, and other source control programs as described in Section 2.12 and discussed in greater detail in Section 9.3 of the SRI (Windward and Anchor QEA 2014). These programs will continue to collect data following the completion of this FS. If necessary, additional findings will be incorporated into post-ROD site-specific remedial design as appropriate.

Direct Discharge

In general, direct discharge systems include municipal or other publicly owned drainage systems, privately owned and managed SDs, and sanitary/combined sewer systems. In addition to direct discharges, some small percentage of stormwater also enters the EW from adjacent properties via sheetflow. As described in the SRI, less than 0.3% of the solids input into the EW are from direct discharges from EW drainage basins. Solids inputs associated with direct discharges to the EW are evaluated in Section 5.

Stormwater is conveyed to the EW by SDs and CSO systems. SDs provide a complete pathway to the EW and include both public and private SD systems. (CSO systems are discussed below). The public SDs are owned and operated by the City or the Port and are covered under their respective National Pollutant Discharge Elimination System (NPDES) municipal stormwater permits and Port tenant industrial permits, where applicable. The USCG facility has coverage under a federal multi-sector general permit. All other drainage systems are classified as private (i.e., outfalls not owned by the Port, City, or USCG).

SDs collect urban runoff from roadways and other upland areas (e.g., commercial, industrial, and residential properties). Urban areas have the potential to accumulate particulate materials, dust, oil, asphalt, rust, rubber, metals, pesticides, detergents, and other chemicals resulting from urban activities and atmospheric deposition. Contaminants present on the ground (e.g., roadways, parking lots, residential yards, or industrial yard areas) can then be flushed into SDs during wet weather and transported to the EW in dissolved or particulate form. These drainage networks also provide a complete pathway for spills and leaks to reach the EW.

CSO discharges are a complete pathway for contaminants entering the EW. CSO events can occur during heavy rainfall when the CSO system capacity is insufficient to transport the volume of both sanitary wastewater and stormwater flows to the wastewater treatment plant. When this capacity is exceeded, excess flow is discharged to the EW through an overflow structure or relief point. CSOs consist of a combination of untreated municipal and industrial wastewater and stormwater runoff. Infrastructure improvements have greatly improved system storage capacity and reduced the number of discharges from CSO systems. Both the County and City have CSO control plans, which will greatly reduce inputs from CSOs in the future.

Sheetflow is a complete pathway where surface water runoff directly enters the EW from berth aprons, deck drains, bridges, and areas immediately adjacent to the EW during rain events. In areas lacking stormwater collection systems potential sources such as contaminated soils or contaminants improperly stored either as raw or as waste materials could be carried directly over these surfaces to the EW.

Upland cleanup sites are also located within EW SD and CSO drainage areas. These sites are of interest for EW sediment recontamination to the extent that they could potentially contribute to elevated contaminant levels in the EW due to lateral discharges that are included in the recontamination evaluation in Section 5.

Groundwater Discharge

Groundwater discharge from upland contaminated sites is a potentially complete pathway for transport of contaminants. Groundwater flow in the surrounding basin is generally toward the EW, although the direction varies locally depending on the nature of subsurface materials, hydrostratigraphy, and proximity to the EW. Near the EW, tidal action influences groundwater flow directions, rates, and water quality. Groundwater discharges into the EW through sediments and seeps observable on the embankment surface during low tide. The determination of whether a contaminant identified in groundwater will impact sediment or surface water quality was presented in the SRI (Section 9.4.4, Table 9-20, Figures 9-20 through 9-24, and Appendix J of Windward and Anchor QEA 2014) and briefly described below.

Extensive nearshore groundwater and seep information is available for nearshore cleanup sites to evaluate the potential for groundwater discharging to the EW to impact sediment quality (Appendix J of the SRI). These data were developed during previous investigation and cleanup activities conducted at many nearshore properties. Three areas were identified with exceedances of groundwater reference values that may be relevant to the evaluation of potential sediment recontamination. These areas included the following:

- Harbor Island: Elevated levels of zinc have been detected in one well (HI-12) located along the shoreline of Harbor Island. No zinc contamination has been detected in nearby EW sediments. Groundwater monitoring continues for this well as part of the compliance monitoring program for the Harbor Island Soil and Groundwater OU.
- Terminal 30: PAH parameters acenaphthene, fluorene, and phenanthrene were detected slightly above groundwater reference values in five nearshore wells (MW-84B, MW-85B, MW-86B, MW-86C, and MW-87B). Nearby sediments exceeded acenaphthene, fluorene, and phenanthrene SQS sediment criteria adjacent to the T-30 property, but did not exceed the CSL criteria. The Port and Ecology are evaluating these data as part of the ongoing investigation and cleanup of this site.
- Pier 35 (USCG): Elevated levels of arsenic were detected in one well (SB-SC-05) located at the USCG property. The detected arsenic value exceeded the groundwater reference value based on protection of sediment quality, and arsenic concentrations exceeded CSL sediment criteria adjacent to the USCG property. Results indicate that the measured arsenic concentration at one location is a potential concern for sediment recontamination based on the natural background value (7 mg/kg dw), but would not be expected to cause an exceedance of the benthic sediment cleanup objective (SCO) value (57 mg/kg dw). Comparing to natural background-based reference values is conservative for analysis of point-by-point groundwater quality data, because this does not consider the effects of spatial averaging relevant to the risk exposure scenarios on which the RBTCs are based. No groundwater monitoring is ongoing at the USCG facility. Groundwater source control at the USCG property may be addressed programmatically by EPA and/or Ecology, or may be evaluated and addressed as part of remedial design.
- T-25: Elevated levels of acenaphthene were detected in one well (AQ-MW-1) located on the T-25 property. The detected acenaphthene values exceeded the reference values based on protection of sediment quality. Several PAHs, including acenaphthene, exceeded the CSL sediment criteria adjacent to the T-25 property, which is within an existing field of creosote-treated timber pilings. Elevated

concentrations of acenapthene in nearshore groundwater are attributed to tidal exchange of PAH contamination in the intertidal bank sediments associated with creosote-treated timber structures present adjacent to the nearshore monitoring wells (Anchor QEA 2012b). Additionally, results of past studies in the upland property area do not identify sources of acenaphthene. No groundwater monitoring is ongoing at T-25. Groundwater source control at T-25 may be addressed programmatically by Ecology or may be evaluated and addressed as part of remedial design.

Groundwater discharges are not accounted for in the sediment transport evaluation (Section 5). As discussed in the SRI (Section 9.4.4, Table 9-20, Figures 9-20 through 9-24, and Appendix J), groundwater has been remediated at several sites around the EW under state and federal cleanup programs to address potential ongoing fluxes of groundwater contamination to the EW. Groundwater is being monitored to ensure that remedies remain protective. The resulting groundwater mass transfer to sediment through equilibrium partitioning is likely to be localized and insignificant compared to other mass inputs to the EW (i.e., sedimentation). Groundwater monitoring data will be used to confirm the absence of a source of contamination to EW sediments during the source control sufficiency evaluation in remedial design and during 5-year reviews.

Bank Erosion

Unprotected bank soils can be susceptible to erosion through surface water runoff, wind waves, and the action of vessel wakes and propwash. If shoreline soils are contaminated, erosion can represent a complete pathway of pollutants to the EW. The presence of shoreline armoring and vegetation affect the potential for bank erosion. Bank slope and soil properties are also factors in the susceptibility of bank areas to erosion; steeper banks are more susceptible to erosion for any given grain size. Currently, nearly all of the EW shoreline is armored with constructed steel, wood, and concrete bulkheads; sheetpile walls; and riprap revetments, which reduce the potential for bank erosion. A small percentage (less than 3%) of the banks contain non-engineered rubble armored slope or non-engineered mud or gravel. No banks were characterized as non-engineered steep banks resulting in higher potential for bank erosion.

The banks that were identified for additional considerations underlie the Spokane Street Bridge (Bank 8B) and adjacent to the USCG Facility (Bank 1 and 2B) as shown in Maps 9-25a through 9-25c of the SRI (Windward and Anchor QEA 2014). These banks are considered as part of alternative development in Section 8. Further evaluations may also be required as part of the post-ROD remedial design.

Atmospheric Deposition

Chemicals are emitted to the air from both point and non-point sources. Point sources include emissions (e.g., "stack emissions") from various stationary (i.e., "fixed" or immobile) industrial facilities (EPA 2001). Non-point sources include emissions from mobile sources such as motor vehicles, marine vessels, and trains, as well as emissions from common materials (e.g., off-gassing from plastics) and road dust resulting from urban traffic. Chemicals emitted to the air may be transported over long distances, generally in the direction of the area's prevailing winds. They can be deposited from the atmosphere to land and water surfaces through wet deposition (precipitation) or dry deposition (as particles) and are a complete pathway to the EW.

Air pollutants can enter waterbodies through either direct or indirect deposition. Direct deposition occurs when particulates with adsorbed chemicals are deposited onto the surface of a waterbody and then settle to the bottom, becoming part of the sediment. Indirect deposition occurs when chemicals are first deposited on land or other waterbodies in the watershed (e.g., streams and lakes) and then transported to the waterbody via surface water or stormwater runoff. Air pollutants deposited in the drainage basin can be transported either in dissolved form or adsorbed to solids in the runoff and are ultimately transported to bottom sediments and the water column. Many air pollutants deposited through direct or indirect atmospheric deposition in aquatic systems, such as the EW, have the potential to contaminate sediment because they are hydrophobic and tend to adhere to sediment particles (PSCAA 2003).

Direct air deposition mass transfer has not been evaluated as part of the pathway characterization. After the submittal of the SRI, King County completed the *Lower Duwamish Waterway Source Control: Bulk Atmospheric Deposition Study Draft Data Report* (King County 2013). The updated atmospheric data and select historical studies (King County 2008) are evaluated in Section 9.

Indirect air deposition was included as part of the direct discharge pathway characterization data (SDs and CSOs) in the SRI (Windward and Anchor QEA 2014). Mass transfer associated with indirect atmospheric deposition (and deposited to the EW via direct discharge) is incorporated into Section 5 evaluations.

Spills and Leaks

Spills and leaks, containing chemical contamination, to soil, other ground surfaces (such as roadways), or surface water are a potentially complete pathway to the EW. Leaks can occur from pipes and storage tanks, industrial or commercial equipment, and process operations. Spills can occur accidentally during vehicle fueling and maintenance, or purposefully in the case of illegal dumping. Spills can be a complete pathway when they discharge directly to the EW via nearshore or overwater operations, or a source when indirectly discharged into SDs or combined sewer systems with CSOs to the EW or by movement through soil to groundwater or erosion of impacted soil. Spills occurring in upland areas are incorporated into the direct discharge pathways (SD and CSO), which is further evaluated in Section 5. Spills directly to the EW are considered potential recontamination sources inherent in any commercial/industrial waterway. Any future spills in the EW will be managed under existing spill prevention and response programs and evaluated for sediment recontamination potential on a case-by-case basis.

Abrasion and Leaching of Treated-wood Structures

Historically, pilings and other wooden structures treated with creosote or other preservatives were commonly used as part of navigation or berthing improvements (e.g., wooden pier and wharf structures, fender systems, and dolphins) and marine structures (e.g., wooden bulkheads). These treated-wood structures are a potential source of contaminants, which can be released to sediments by abrasion or leaching pathways. Studies at other sites in the region indicate that the impact of treated-wood structures on sediments tends to be localized and results in steep concentration gradients of contaminants in sediments within a few feet from structures (e.g., Goyette and Brooks 1998; Poston 2001; Weston and Pascoe 2006). Although abrasion and leaching of pilings are not accounted for in the sediment transport evaluation (Section 5), the FS baseline dataset shows patterns that are consistent with these findings.

Transport of Surface Water and Sediment

Surface water inputs and suspended sediment are transported to the EW from upstream (the Green/Duwamish River and LDW) and from Elliott Bay. The input amounts and types vary greatly during the year; the Green/Duwamish system is variable, and it can be influenced by ongoing contaminant inputs from a large area of mixed industrial, commercial, residential, and agricultural lands. The LDW upriver of the EW is also a CERCLA site with contaminated sediments. Contaminants (both dissolved and particulate) released from outside of the EW drainage basins have the potential to enter the EW through transport of sediments and water from upriver or Elliott Bay. As presented in the SRI (Windward and Anchor QEA 2014) sediment contaminant levels were lowest in the northern portion of the EW, adjacent to Elliott Bay. Sediments in this area are below SQS chemical and/or biological testing criteria, suggesting that transport of Elliott Bay sediments to the EW does not pose a significant potential for sediment recontamination.

As described in the SRI (Windward and Anchor QEA 2014), 99% of the incoming solids to the EW are from the Green River and approximately 0.7% are from the LDW (bed sediments and lateral loads). Based on the evaluations in the SRI, solids from Elliott Bay are negligible in relation to other mass inputs. Sediment transport into the EW is a complete pathway and is evaluated in Section 5.

2.12 Source Control

Understanding ongoing sources of contamination and their potential impact to EW sediments is an important consideration for the cleanup of the EW. As such, an extensive source control evaluation was conducted as part of the SRI/FS.

The goals of the source control evaluation work for the SRI/FS were defined in the Work Plan (Anchor and Windward 2007) and include the following:

- Identifying potential sources of contamination to EW sediments
- Understanding the potential for these sources to recontaminate the EW sediments
- Assessing the role of ongoing sources on the CSM for the EW
- Defining a process for identifying source control data gaps, and identifying a process for collecting relevant field data, if necessary

- Providing a basis for the evaluation of potential sources through efforts such as inspections, investigation, or other actions and identifying the processes and authorities for source control activities in the EW area
- If applicable, a prediction of potential recontamination and its effect on a cleanup decision

The Source Control Evaluation Approach Memorandum (SCEAM) describes the source control evaluation process and strategy in greater detail (Anchor and Windward 2008b). Specific source control data needs for the SRI/FS were defined in the Initial Source Control Evaluation and Data Gaps Memo (Anchor QEA and Windward 2009).

In support of the SRI development, extensive source characterization and control efforts have been conducted, supplementing data available from other ongoing programs. These existing and new data were used to characterize the pathways by which ongoing contaminant source inputs can reach and impact the EW sediments. These data also support the evaluation of potential sediment recontamination as part of this FS (see Section 5). These evaluations have been and will continue to be factored into source control decisions, which will continue during the source control sufficiency evaluation conducted during remedial design.

2.12.1 Source Control Strategy

The EW source control strategy includes continued evaluation of each of the potential ongoing source pathways listed in Section 2.11.3.2. The strategy for most source pathways is to continue to rely on existing laws, permits, and other requirements that are already in place and will continue to be in place during and after sediment cleanup. The bank erosion and abrasion and leaching of treated-wood structures source pathways are expected to be addressed as part of the remediation. Each of the existing source control-related programs will continue to generate information relevant to EW source control during the FS and through the ROD. The Port, City, County, and potentially additional parties will continue source control efforts, with reporting to EPA throughout these periods in regular EW source control update meetings.

Following issuance of the ROD, implementation planning and design for the cleanup of the EW sediments will integrate and enhance, as necessary, the evaluations of the existing source control programs. During remedial design, source control sufficiency will be evaluated to assess whether sources have been controlled to the extent necessary to commence remediation of sediments. The Port, City, County, and other parties as needed (e.g., USCG), will provide information generated as part of each source control program and make sufficiency recommendations to EPA. Information provided during this process is expected to be similar to what is currently provided as part of regular EW source control update meetings. The criteria for source control sufficiency and the phasing of source control work relative to the phasing of cleanup will be developed during remedial design. After the implementation of cleanup, the set of source control-related (discussed below) programs will continue to regulate discharges to the EW to reduce the potential for recontamination of EW sediments.

2.12.2 Source Control-related Programs

A detailed discussion of ongoing source control programs and activities was presented in Section 9.3 of the SRI (Windward and Anchor QEA 2014). The majority of the source control evaluation in the EW to date has been performed under other programs and regulations, such as NPDES (e.g., for stormwater and CSO discharges) and Model Toxics Control Act (MTCA) (e.g., for upland cleanup sites adjacent to the EW). These programs enforce stringent federal and state standards (e.g., the Clean Water Act [CWA]), and incorporate reporting and review cycles for transparency, corrective action, and adaptive management. A summary of each source control-related program and how it relates to the source control strategy is provided below:

NPDES: NPDES discharges are generally administered by Ecology, although USCG discharges are administered federally. NPDES-permitted discharges to the EW include industrial and municipal stormwater, stormwater originating from certain construction projects, and County and City CSOs. Regular monitoring and reporting is conducted as part of these programs. The continued implementation of permitted discharges requires the integration of pollutant-reducing best management practices (BMPs).

CSO Control Programs: CSO control programs by the County and City under the NPDES program (and consent decrees) will also contribute to source control in the EW. These are administered by Ecology. The County and the City also have operations and maintenance programs for the combined systems.

Compliance and Inspection Programs: The Port, County, and City conduct various inspections/site assessments, based on their applicable regulatory authority, to enhance or assess compliance of permitted dischargers. These programs will continue during and after remediation. The continued inspection and assessment of businesses and tenants operating in the EW basin to enforce or enhance compliance with source control requirements through the implementation of appropriate BMPs reduces recontamination potential.

East Waterway Source Tracing Activities: The City, County, and Port will continue to conduct source tracing and identification sampling activities to support the EW source control efforts. Source tracing sampling is designed to identify potential sources by strategically collecting samples at key locations within the storm drainage and combined sewer service areas. Additional activities may be conducted to support source control sufficiency evaluation. Source tracing and source control efforts will continue through remedy implementation to minimize potential recontamination from direct discharges from stormwater outfalls and CSOs.

Municipal Stormwater Management: Both the City's and the Port's municipal stormwater permits require development of a stormwater management plan to meet CWA and state water quality requirements. Continued implementation of municipal codes require integration of pollutant-reducing BMPs.

Site Cleanup and Associated Programs: Upland soil and groundwater adjacent to the EW has been cleaned up and monitored under Ecology-administered (MTCA) and EPA-administered (CERCLA) programs. Completion of groundwater monitoring programs will verify the protectiveness of upland remedies at state and federal cleanup sites with respect to EW sediment recontamination. Further evaluation of USCG property bank soil and groundwater quality will minimize the recontamination potential in the EW sediments in this area. Upstream sediments have been, and will be, cleaned up under CERCLA, MTCA, and

Resource Conservation and Recovery Act (RCRA) administration. The LDW cleanup and source control activities may reduce the potential for recontamination of EW sediments from ongoing upstream inputs. Timing of the LDW cleanup will be considered as part of source control sufficiency for the EW.

Spill Response: Ecology, USCG, the Port, and Seattle Public Utilities (SPU) maintain spill response programs that support source control efforts in the EW. Ongoing operation of spill prevention and response programs within the EW and its drainage basins reduces recontamination risks.

Air Quality Programs: Numerous state, federal, and local programs exist to evaluate air quality and control potential air pollution sources. Air quality and atmospheric deposition information has been collected in the vicinity of the EW by several groups, including the Puget Sound Clean Air Agency (PSCAA), Ecology, and the County. If additional information is collected in the future, it will supplement existing information.

Bank erosion and abrasion and leaching of treated-wood structures pathways will be addressed directly during cleanup. Both of these potential sources are located within the limits of the EW and will be evaluated as part of remedial design. Bank stability is an important component of dredging and capping design and will be addressed as part of geotechnical analysis. The impact of treated-wood structures within the EW (e.g., the Former Pier 24 Piling Field) will be evaluated during design and addressed as necessary by the selected alternative. Some piling removal has already been performed by individual parties in the EW, including as part of a DNR program for the removal of creosote-treated structures. Ongoing treatment, replacement, and/or removal of treated wood structures located within the EW as needed during redevelopment reduces the potential for recontamination from these sources.

2.13 Key Observations and Findings from the SRI

Key observations and findings for the SRI (Windward and Anchor QEA 2014) are summarized below:

- Over the past 100 years, the EW has been highly modified from its natural configuration of a river mouth delta to support urban and industrial development. Changes have included reductions and control of water flow, channel deepening, significant shoreline modifications, fill of shorelines, loss of intertidal habitat, and installation of riprap, pier aprons, and sheetpile walls.
- Commercial and industrial facilities are the predominant use of the shoreline.
- The EW is currently and expected to continue to be used as a commercial navigational corridor. In addition to commercial activities, the EW supports the collection of seafood by tribal members, who have tribal treaty rights to harvest seafood from EW, as well as others such as recreational fishers or individuals collecting seafood to supplement their diet.
- Despite significant habitat alterations and the presence of areas with elevated contaminant concentrations in sediment, the EW contains a diverse assemblage of aquatic species and a robust food web that includes top predators.
- The site-wide average rate of sediment deposition in the EW is approximately 1.2 cm/yr.
- Results of the LDW sediment transport modeling completed and results of the PTM for lateral sources within the EW suggest that 99% of the sediment input into the EW is from the Green River, approximately 0.7% is from the LDW (bed sediments and lateral inputs), and less than 0.3% is from discharges within the EW itself (e.g., stormwater and CSOs).
- The Deep Main Body Reach, the Shallow Main Body Reach, and the Junction Reach may experience episodic or occasional erosion or re-suspension of surface sediments due to propwash.
- Sediment concentrations above the SMS were measured throughout the EW. The majority of the contaminant concentrations above CSL values in surface sediment were located in areas within the EW that have not recently been dredged (i.e., the Shallow Main Body Reach, the perimeter of the Deep Main Body Reach, and the slips). The locations of the highest total PCB, cPAH, arsenic, mercury, and TBT concentrations were varied.
- The distribution of contaminants in subsurface sediment was found to be similar to the distribution in surface sediment. In recently dredged areas, the subsurface sediment concentrations were generally less than the surface sediment

concentrations. However, in the Shallow Main Body Reach and areas within the Deep Main Body Reach that have not been recently dredged, the subsurface contaminant concentrations were generally greater than the surface sediment concentrations. The contaminants that exceeded the SMS in the greatest number of subsurface samples were total PCBs and mercury.

- In surface water samples in the EW, chronic aquatic life water quality criteria (WQC) were exceeded (and detected) in one sample for both cadmium and TBT. Human health WQC were exceeded (and detected) in multiple samples for arsenic[17] and total PCBs, and in no more than three samples for benzo(a)anthracene, chrysene, and BEHP.
- In groundwater samples collected from sites adjacent to the EW, chronic aquatic life WQC were exceeded for arsenic, copper, nickel, and zinc in one or more samples, and acute aquatic life WQC was exceeded for arsenic in one sample.
- Key pathways and sources of contaminants were identified, with potential sources of contaminants being the result of both historical and ongoing inputs. Source control data are available for the different pathways to evaluate recontamination potential of sediments in the FS. This evaluation will inform future source control actions in EW.

2.14 Additional Considerations for the FS

In this section, data presented in the SRI (Windward and Anchor QEA 2014) are expanded upon for the purposes of this FS. This section also discusses information not presented in the SRI that may be relevant to selecting remedial technologies and developing remedial alternatives.

2.14.1 Sediment Physical Properties

The geotechnical and physical properties of sediment (such as density, plasticity, sediment grain size, and the presence of debris) are important for developing appropriate remedial technologies. Some of the important technology considerations affected by sediment physical properties include:

[17] Note that the SRI (Windward and Anchor QEA 2014) water data represent total arsenic (i.e., the sum of the organic and inorganic arsenic species) and the criterion represents the inorganic fraction of arsenic only, so these exceedances are uncertain.

- Dredgeability or the ability to physically excavate the sediment
- Sediment handling
- Sediment dewatering
- Slope stability
- Bearing capacity for cap placement
- Consolidation settlement of sediments under cap loads

Geotechnical properties such as grain size composition, plasticity, porosity, and unit weight (as measured by bulk density) were evaluated to help understand the manner in which sediment could behave when handled during remediation.

Supplemental geotechnical testing was performed on a subset of the EW SRI subsurface sediment dataset, which included 13 subsurface core locations generally evenly distributed across the EW. Geotechnical tests included Atterberg limits (i.e., liquid limit, plastic limit, and plastic index), specific gravity, moisture content, and bulk density (dry and wet). Testing was performed on intervals that represented the major subsurface sediment units. Geotechnical properties vary with depth and with sediment type, and are summarized by EW stratigraphic groupings. In general, moisture content decreases with depth and dry bulk density increases with depth, as would be expected due to the more consolidated nature of the deeper sediments. More consolidated sediments generally have greater strength, which decreases ease of dredging but tends to increase support for sediment caps. Additional details on the geotechnical results are presented in the subsurface sediment data report (Windward 2011).

2.14.1.1 Engineered Fill, Anthropogenic Fill, and Sand Cover Layers

These layers are typically surficial within the top 1 foot below mudline. These materials are typically granular, with dry bulk density ranging from 92 to 97 pounds per cubic foot [pcf], wet bulk density ranging from 107 to 110 pcf, moisture content ranging from 14% to 15%, and a typical specific gravity of 2. 7 grams per cubic centimeter [g/cm^3]).

2.14.1.2 Recent Unit

Geotechnical tests were performed on near-surface (0 to 3 feet below mudline) recent silts. These shallow silts exhibit a range of dry bulk density from 34 to 47 pcf, a range of wet bulk density from 67 to 85 pcf, and a range of moisture content from 82% to 110%. The mean specific gravity is 2. 53 g/cm^3. Atterberg limits data indicate a mean liquid limit of 77.1% dw, a mean plastic limit of 28.2% dw, and a mean plasticity index of 48.9% dw.

2.14.1.3 Upper Alluvium Unit

Mid-depth Upper Alluvium layers (generally 2 to 5 feet below mudline) included a wide range of silts, silty sands, and silt with laminated and stratified beds of sand. Geotechnical properties span relatively larger ranges of values and are indicative of the varied nature of material in this stratigraphic layer. Dry bulk density values range from 53 to 89 pcf, wet bulk density values range from 84 to 119 pcf, and moisture content values range from 23% to 60%. Mean specific gravity is 2.65 g/cm^3. Atterberg limits tests indicate a mean liquid limit of 46.8% dw, a mean plastic limit of 23.4% dw, and a mean plasticity index of 23.4% dw.

2.14.1.4 Lower Alluvium Unit

Deeper Lower Alluvium layers (up to 10.8 feet below mudline) included a wide range of lithological composition, but generally consist of a predominantly sand matrix with laminated beds of silt. Dry bulk density ranges from 54 to 99 pcf, wet bulk density values range from 72 to 125 pcf, and moisture content values range from 24% to 42%. Mean specific gravity is 2.65 g/cm^3. Atterberg limits indicate a mean liquid limit of 37% dw, a mean plastic limit of 28.8% dw, and a mean plasticity index of 8.2% dw.

2.14.2 Debris

Submerged and emergent debris and obstructions can have a substantial impact on the selection and application of appropriate remedial technologies and overall performance of the EW remediation, particularly as it relates to dredge production rate and the generation of residuals. Encountering debris and submerged objects can damage dredge buckets and clog cutterheads, slow production, cause substantial material release of sediments out of partially opened buckets or flushed hydraulic pipelines, and, in general, impact the ability of a dredging operation to achieve cleanup standards in an effective manner. Industrial waterways such as the EW typically contain debris, deposited over decades of waterway use.

It is not feasible to fully quantify the type and vertical extent of all the debris that will be encountered during dredging until dredging is under way; however, design-level debris assessment can qualitatively identify some surficial or buried debris, including side-scan sonar, magnetometer, and diver surveys. Debris sweeps are assumed to be a part of the dredging activities for all remedial alternatives.

2.14.3 Recent Dredging Events

As described in Section 2.2, portions of the EW have been dredged multiple times since its original construction in the early 1900s. Dredging in the EW has been conducted to maintain and deepen existing berths and to deepen part of the federal navigation channel to -51 feet MLLW. Recent dredge events are summarized below and illustrated in Figure 2-22 for events occurring from 2000 to 2016:

- Stage 1 navigational dredging (December 1999 to February 2000) to -51 feet MLLW from the north end of the EW to Station 4950.
- T-30 berth dredging (2002) to -44 feet MLLW (Stations 1400 to 2900).
- Phase 1 Removal Action dredging (January 2004 to February 2005) to -51 feet MLLW (Stations 3000 to 4950). Contingency dredging occurred to -52 to -53 feet MLLW over most of the dredge footprint, which was followed by placement of sand cover material with a minimum thickness of 6 inches. Sand layer thickness measured after placement ranged from 6 inches to more than 1 foot and averaged 10 inches (Anchor and Windward 2005).
- Slip 36 dredging (August 2004 to February 2005) to -40 feet MLLW.
- T-46 maintenance dredging (2005) to -51 feet MLLW (Stations -200 to -700).
- T-30 berth deepening (conducted over two dredge seasons from January 2008 to February 2009) to -51 feet MLLW (Stations 1700 to 3500).
- T-18 dredging in Berths 2 through 5 (January 2005 to November 2006) to -51 to -52 feet MLLW (Stations 1500 to 4950).
- T-18 minor maintenance dredging (January and February 2009) to -51 feet MLLW (less than 1,000 cubic yards [cy] removed [Stations 500 to 4900]).
- T-18 maintenance dredging (February and March 2016) to -51 feet MLLW (approximately 6,200 cy of sediment removed [Stations 0 to 4950]).

Dredge records for events conducted prior to 2000 are limited and exact dimensions are not always known. Based on available data, these older dredging events included the following:

- T-25 (1970s) berth dredging to -50 feet MLLW up to the federal channel boundary.
- T-25 (1981) keyway dredging to -55 feet MLLW from Stations 4250 to 6100. This event included dredging a narrow keyway along the face of Berth 25 for construction of the T-25 riprap slope. The keyway was backfilled with riprap to approximately -50 feet MLLW. The outer edge of the excavation would likely have been less than 25 feet from the face of the pier. The keyway design width was 5 feet and the outer edge sloped from -55 feet MLLW (toe of keyway) to approximately -45 feet MLLW.
- T-30 (1980s) keyway dredging to -55 feet MLLW from Stations 1600 to 3600 before being backfilled with riprap. This keyway dredging was similar to the T-25 keyway dredging described above.

2.14.4 Seismic Conditions

This section summarizes seismic conditions that were presented in LDW FS (AECOM 2012), which are also directly applicable to the EW. The Puget Sound region is vulnerable to earthquakes originating primarily from three sources:

1. The subducting Juan de Fuca plate (intraplate)
2. Between the colliding Juan de Fuca and North American plates (subduction zone)
3. Faults within the overriding North American plate (shallow crustal)

Earthquakes have the potential, depending on epicenter, magnitude, and type of ground motion, to change the vertical and lateral distribution of contaminated sediments in the EW and soil in the EW drainage basin and surrounding upland areas. This potential is considered during the development and evaluation of remedial alternatives in this FS and will be refined during the remedial design phase.

The following are examples of regional earthquakes by source, estimated probability of occurrence in any given 50-year interval, type and date of events that have historically occurred, and their magnitude (Moment Magnitude Scale [M][18]) (EERI and WMDEMD 2005):

- Intraplate (84% probability):
  - Nisqually 2001, M6.8
  - Seattle-Tacoma 1965, M6.5
  - Olympia 1949, M6.8
- Subduction Zone (10% to 14% probability):
  - January 1700, M9 (estimated)
  - Shallow Crustal (5% probability)
  - Seattle Fault (approximately 1,100 years ago), M6.5 or greater

Of particular concern to regional planners is a large earthquake on the Seattle Fault, similar to the one that occurred approximately 1,100 years ago and caused a fault displacement of the bottom of Puget Sound by several feet. The geologic record shows that this earthquake caused a 22-foot uplift of the marine terrace on southern Bainbridge Island, numerous landslides in Lake Washington, and landslides in the Olympic Mountains (Bucknam et al. 1992). Upland sand deposits at West Point, north of Elliott Bay, and at Cultus Bay on the southern end of Whidbey Island (Atwater and Moore 1992) suggest that that earthquake produced a tsunami that deposited up to 10 feet of material in some upland areas.

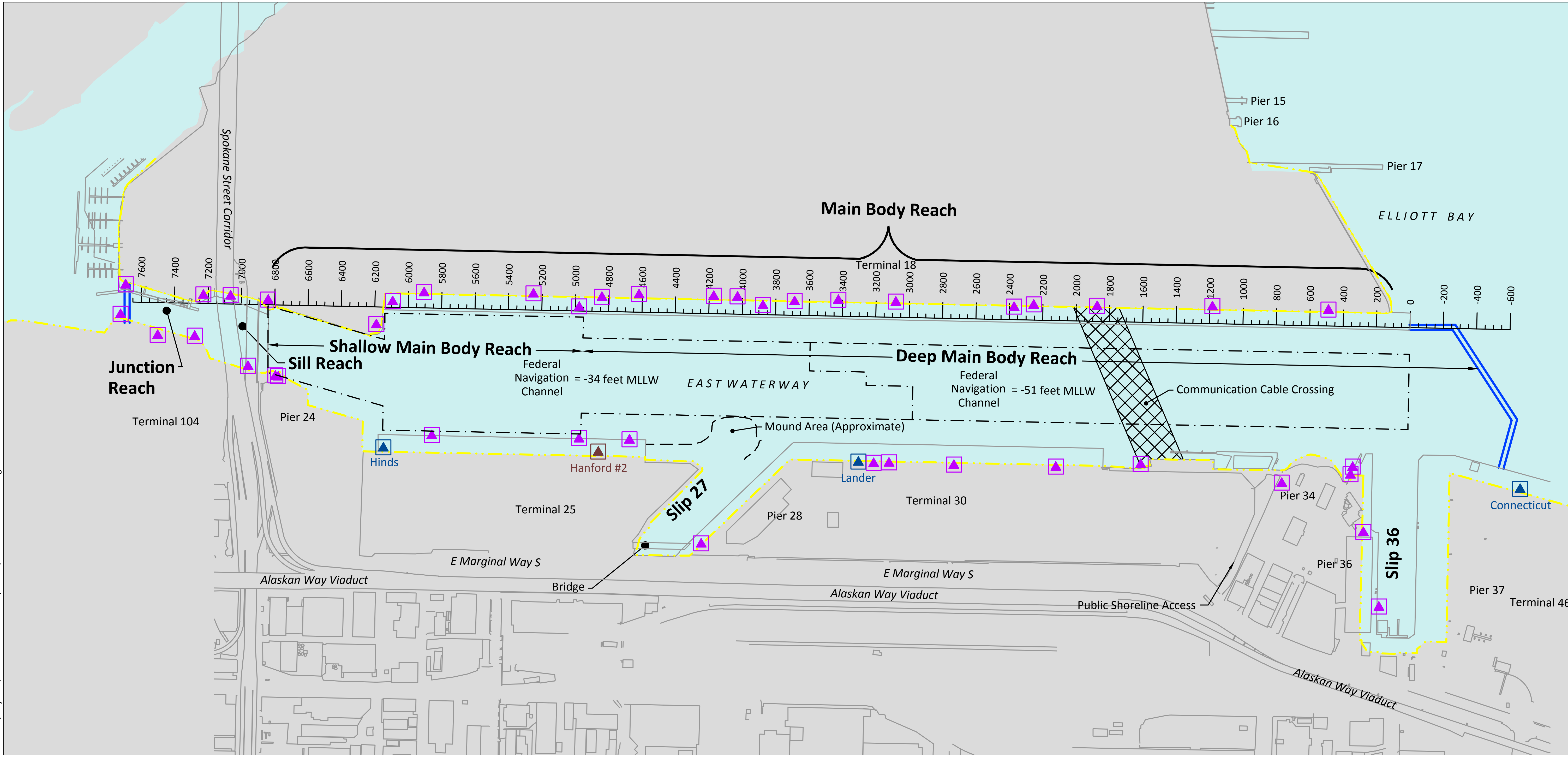
The Seattle Fault is believed to be capable of generating another major earthquake of M7 or greater (Pratt et al. 1997; Johnson et al. 1996, Brocher et al. 2000). A hypothetical Seattle Fault earthquake scenario was developed for guiding regional preparation and responses to such a foreseeable event (EERI and WMDEMD 2005). The earthquake in this scenario was of

[18] The Moment Magnitude Scale (M) is used by the U.S. Geological Survey to measure the size of large earthquakes in terms of the energy released. This logarithmic scale was developed in the 1970s to succeed the Richter magnitude scale. It provides a continuum of magnitude values; moderate events have magnitudes of greater than 5.0 and major earthquakes have magnitudes of greater than 7.0. Great earthquakes have magnitudes of 8.0 or higher. Moment Magnitude considers the area of rupture of a fault, the average amount of relative displacement of adjacent points along the fault, and the force required to overcome the frictional resistance of the materials in the fault surface and cause shearing.

magnitude M6.7, which has an estimated 5% probability of occurrence in any given 50-year period (once in approximately 1,000 years). This scenario is based on a shallow epicenter with a surface fault rupture (as opposed to the deeper epicenters with other recent events such as Nisqually [2001], Seattle- Tacoma [1965], and Olympia [1949]). The Seattle Fault scenario would have major consequences for liquefaction-induced ground movements that could damage in-water and upland infrastructure in the EW and Green/Duwamish River valleys. Under the scenario, ground deformation could be up to 3 feet, which would impact seawalls and release upland soils into the EW. An earthquake of this magnitude would also likely cause widespread disruption of essential services.

Tsunamis could also affect the vertical and horizontal distribution of sediment contamination remaining in the EW following cleanup and could contribute additional contaminants derived from other sources. Titov et al. (2003) modeled a M7.3 earthquake at the Seattle Fault and the resulting tsunami bore was modeled southward to approximately river mile (RM) 1.5 on the LDW. The modeled tsunami would inundate Harbor Island, the South of Downtown District, and uplands along the EW and LDW. The model also predicts some locally high velocities over the bench areas as the bore moves through the EW and lower reach of the LDW. EW soils are classified as being susceptible to liquefaction (Palmer et al. 2004), which would tend to magnify earthquake-induced motion.

Section 8 includes considerations of seismicity with respect to other feasibility studies and remedial designs for other projects in the vicinity of the EW and the adjacent Elliott Bay.



NOTE:
1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.

LEGEND:
- East Waterway Study Boundary
- MHHW Line
- Federal Navigation Channel
- CSO
- Storm Drain
- CSO/Storm Drain

0 600
Scale in Feet

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Jan 08, 2016 12:31pm chewett

Figure 2-1
Major East Waterway Features
Feasibility Study
East Waterway Study Area

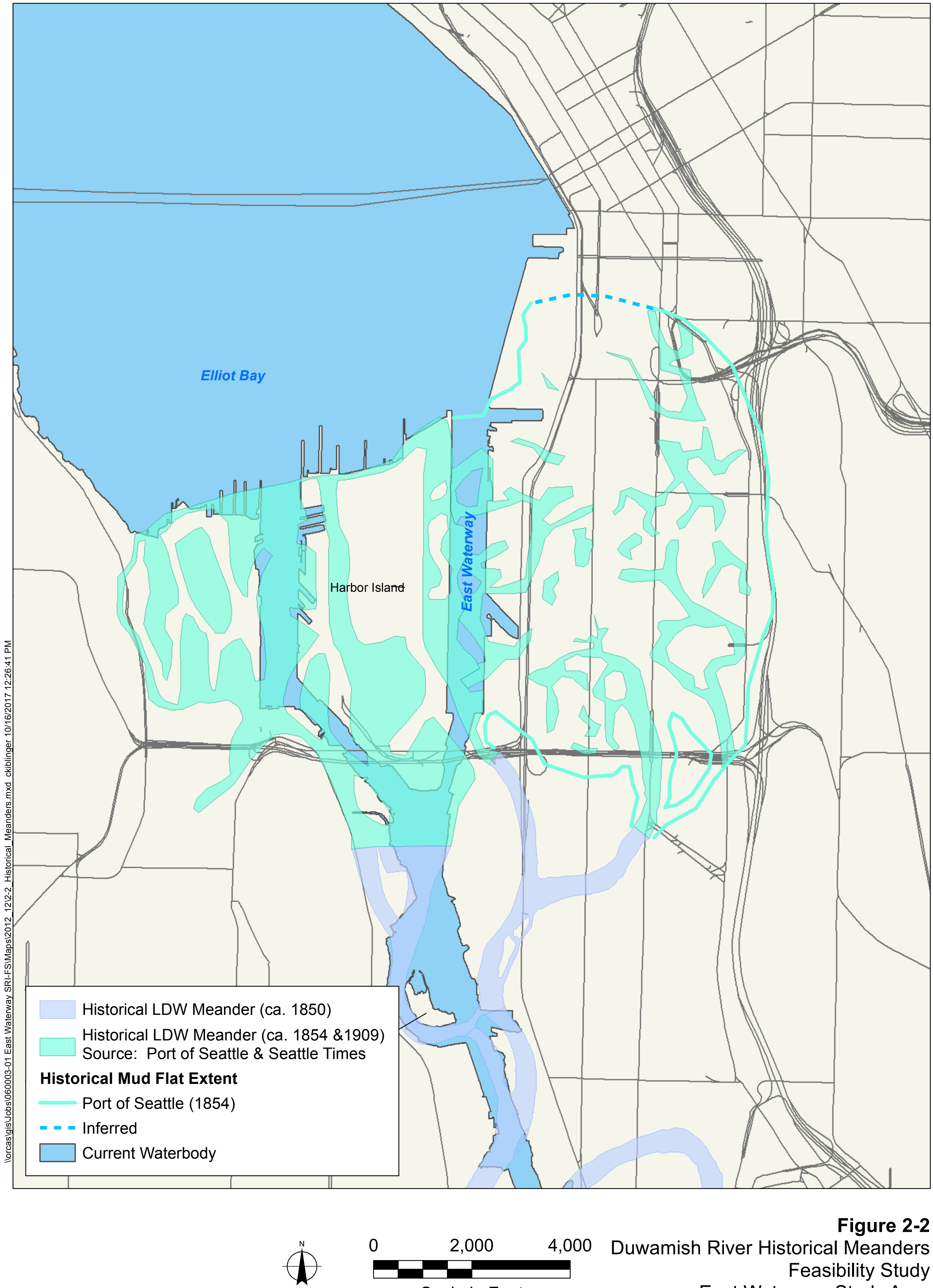


Figure 2-2
Duwamish River Historical Meanders
Feasibility Study
East Waterway Study Area

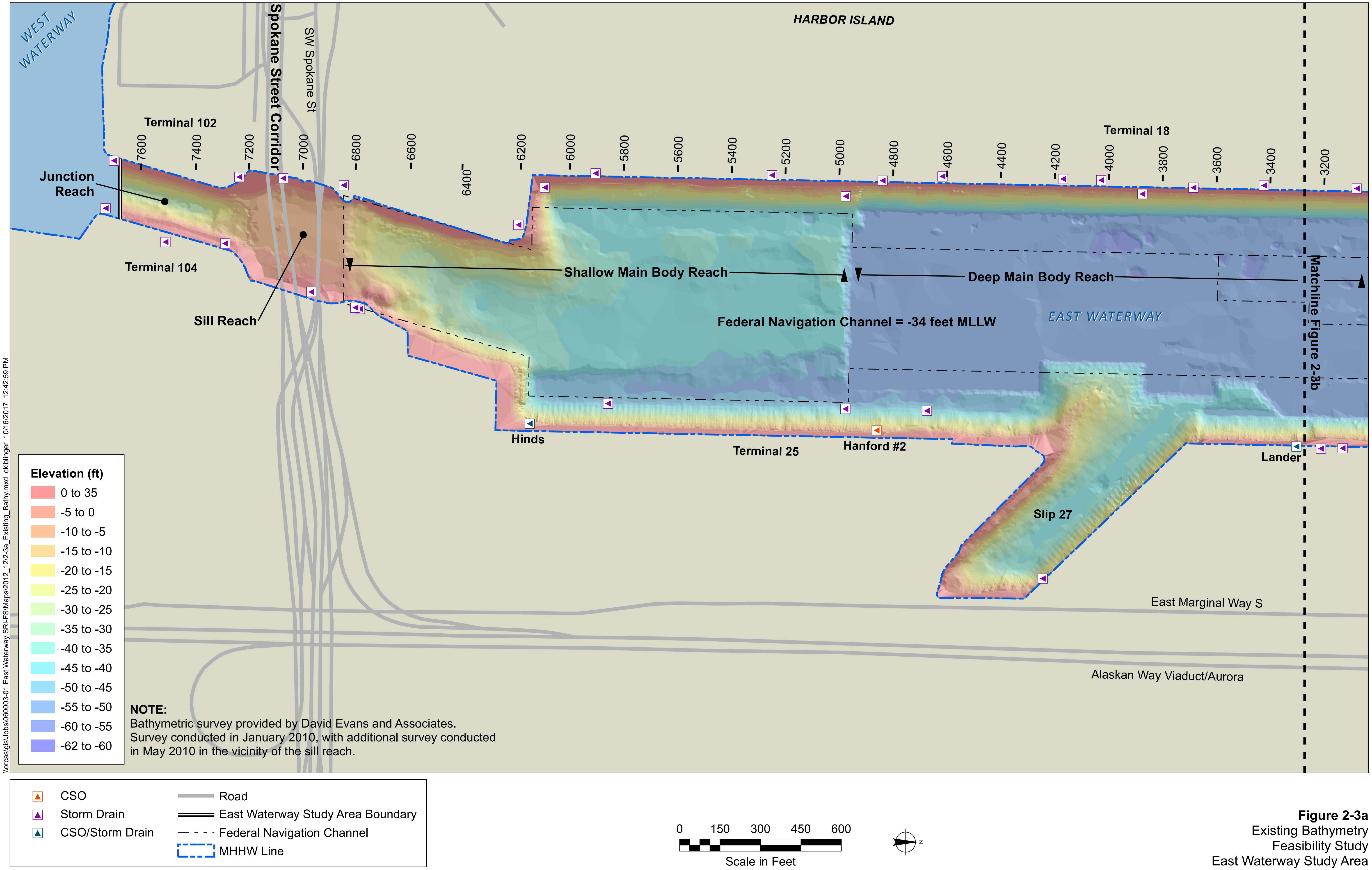
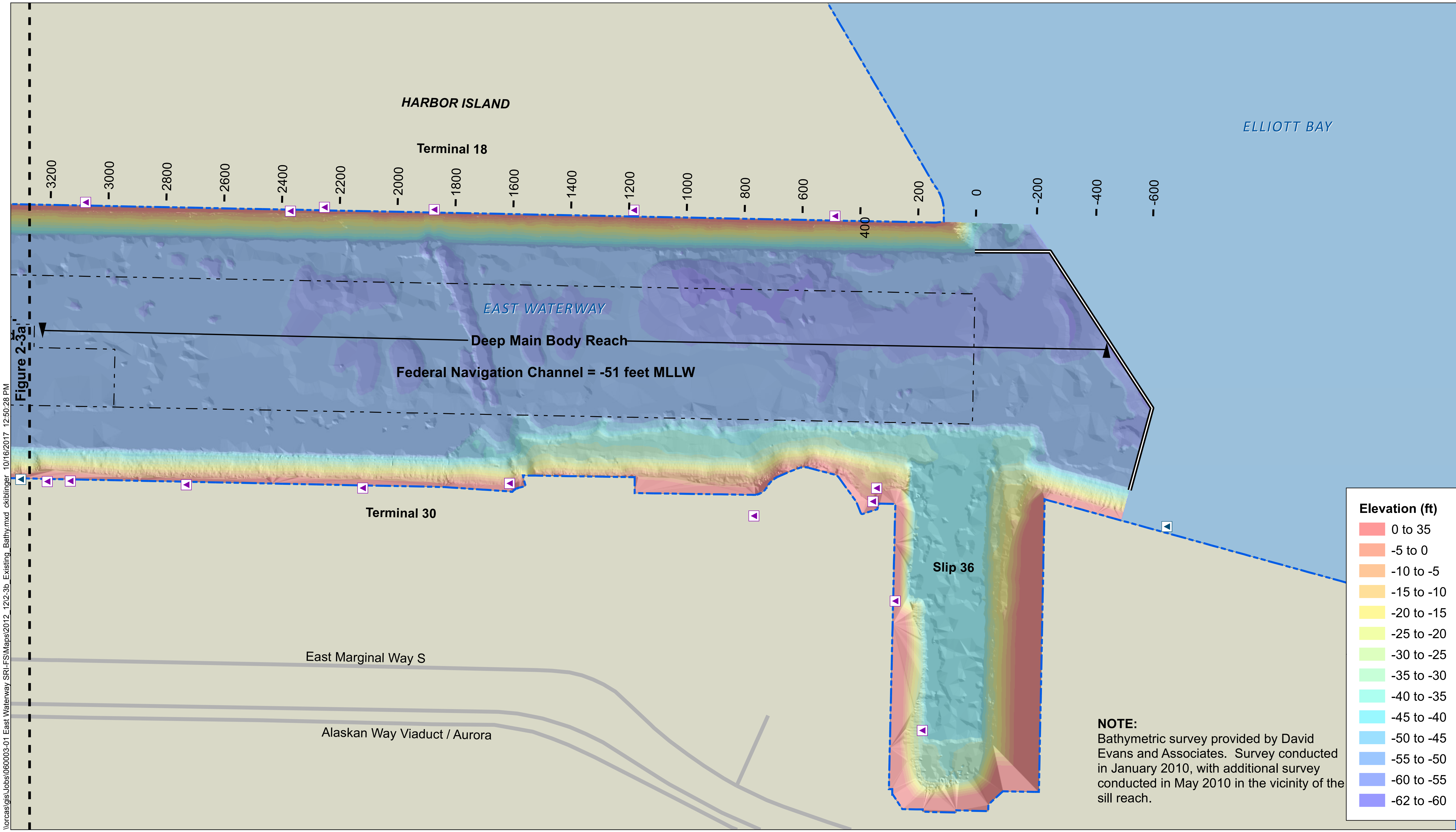


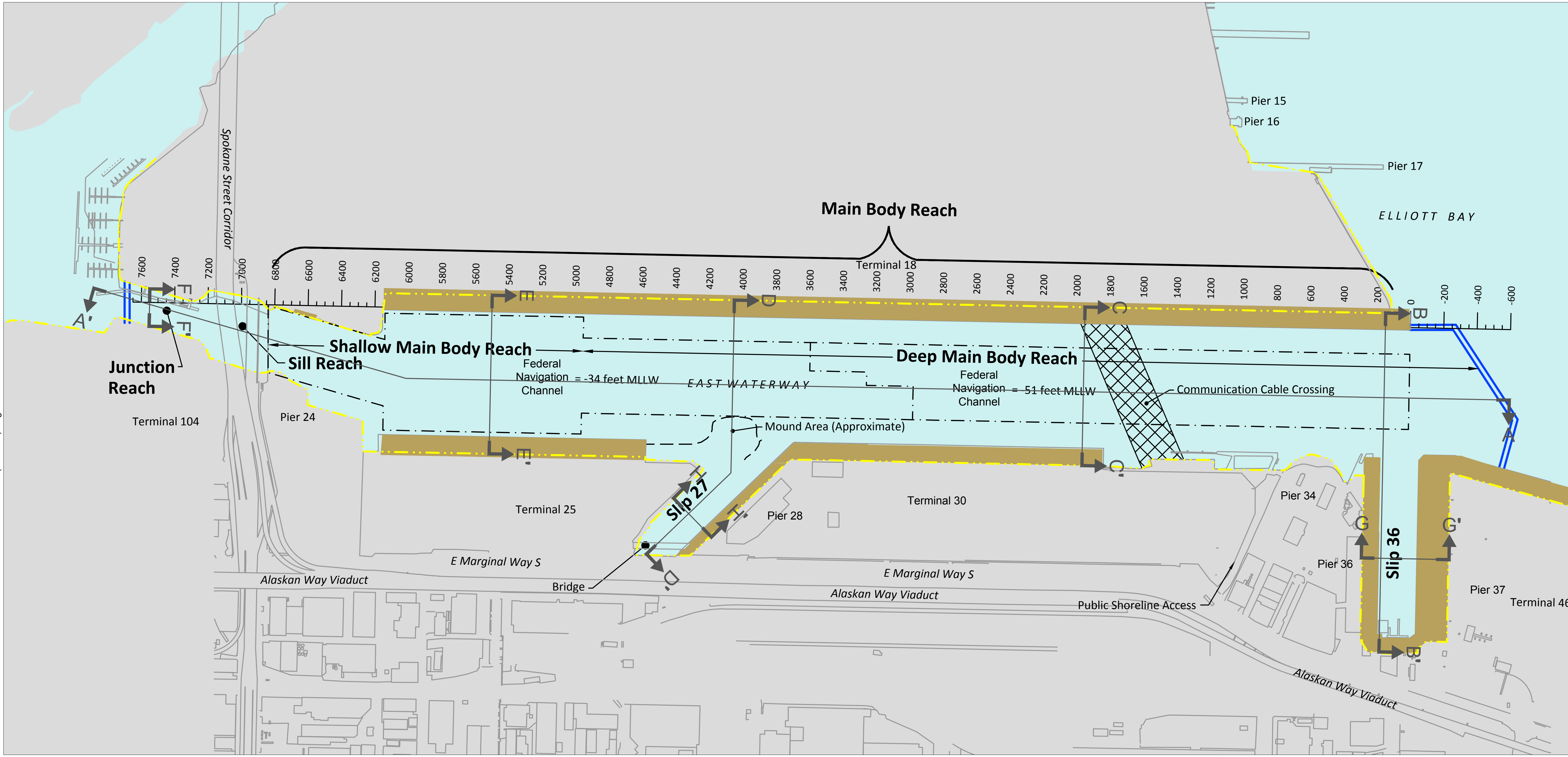
Figure 2-3a
Existing Bathymetry
Feasibility Study
East Waterway Study Area



CSO
Storm Drain
CSO/Storm Drain
Road
East Waterway Study Area Boundary
Federal Navigation Channel
MHHW Line

0 150 300 450 600
Scale in Feet

Figure 2-3b
Existing Bathymetry
Feasibility Study
East Waterway Study Area



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Jan 08, 2016 12:29pm chewett

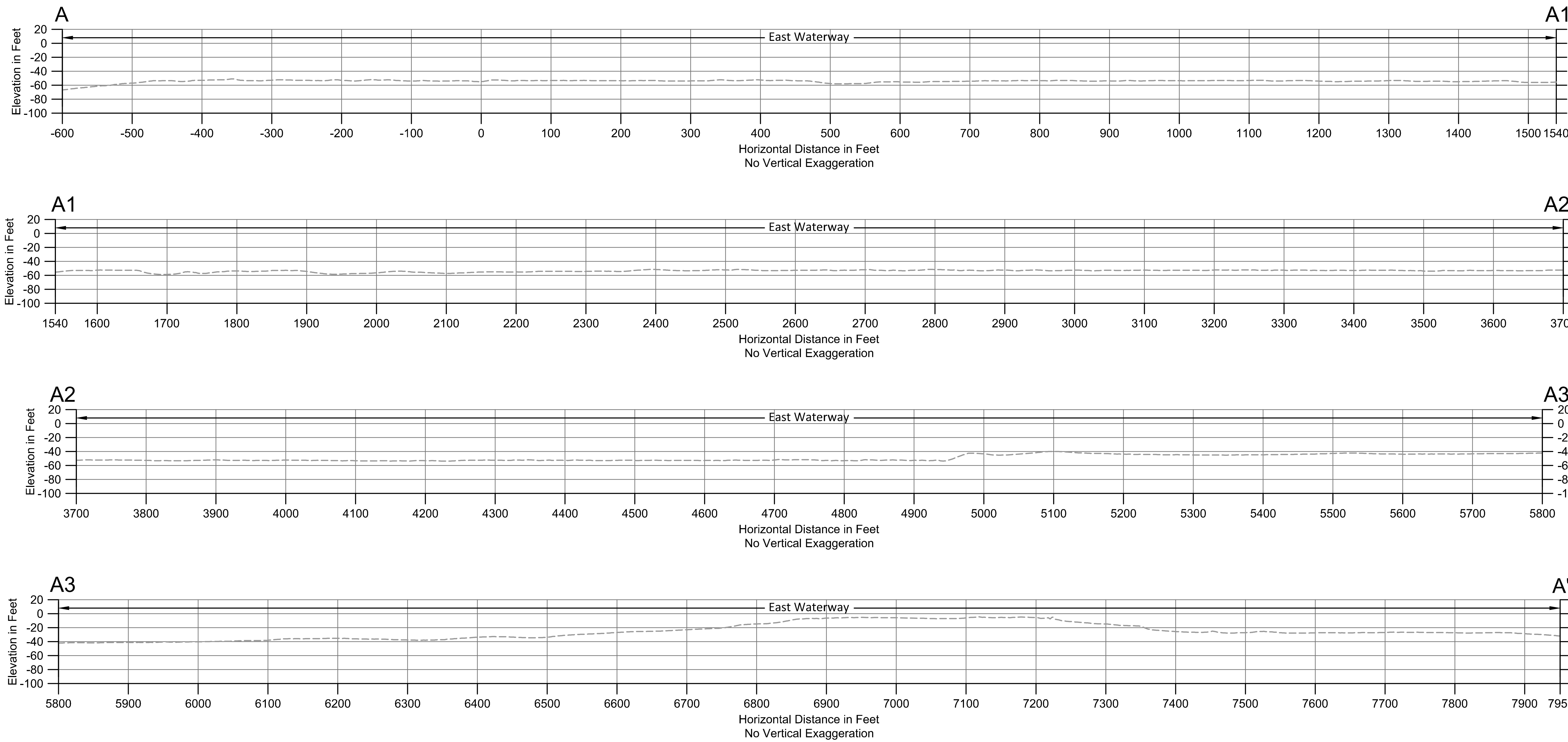
NOTES:
1. Cross-sections are shown on Figures 2-4b-d.

LEGEND:
- East Waterway Study Boundary
- MHHW Line
- Federal Navigation Channel
- Overwater Pier Above Riprap

A A' Cross Section Location

0 600
Scale in Feet

Figure 2-4a
Cross-section Plan View
Feasibility Study
East Waterway Study Area



SOURCE: Existing bathymetry survey provided bv David Evans and Associates.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

NOTES:
1. Cross-section locations are shown on Figure 2-4a.

LEGEND:

------- Existing Mudline

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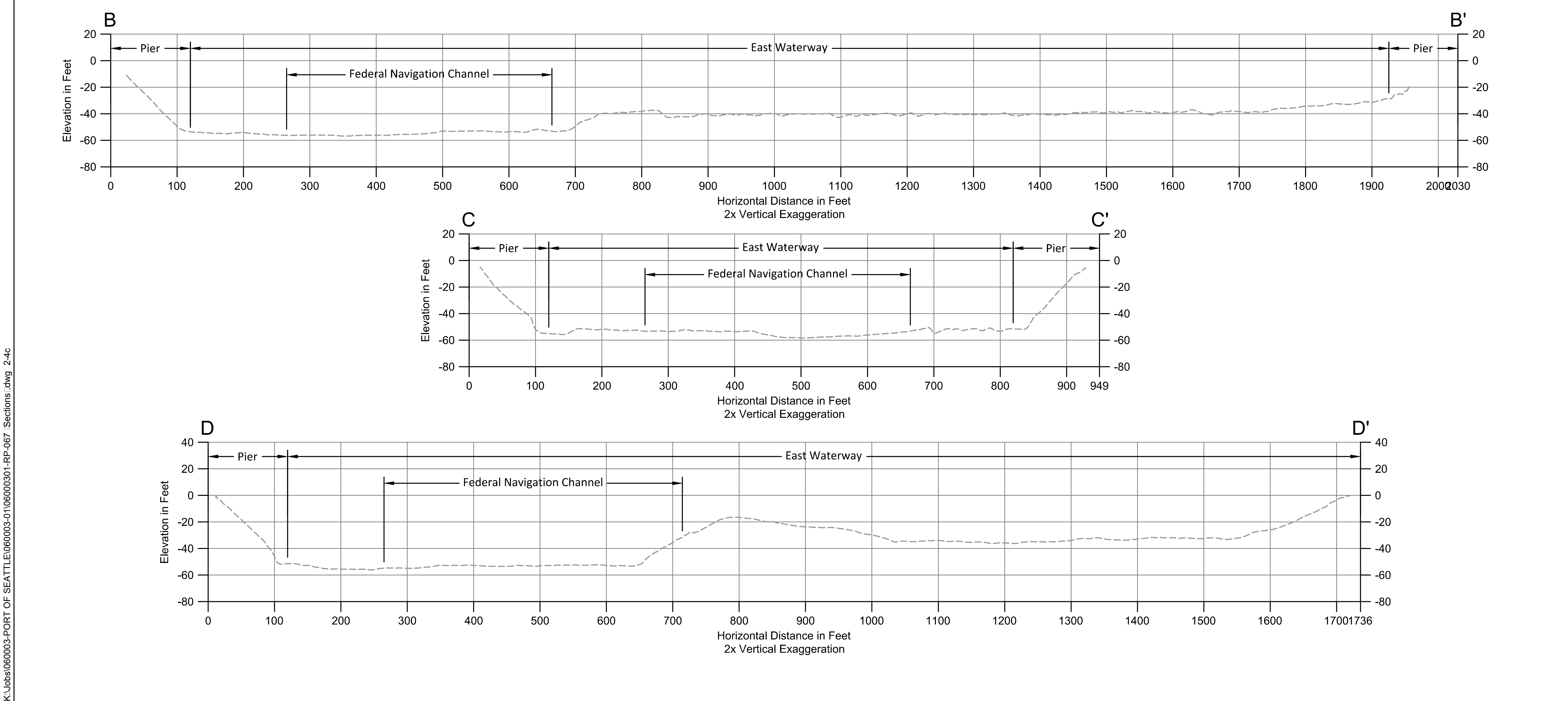
07, 2013 10:1 am chewett

ANCHOR QEA

Figure 2-4b
Cross-sections
Feasibility Study
East Waterway Study Area



SOURCE: Existing bathymetry survey provided bv David Evans and Associates.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

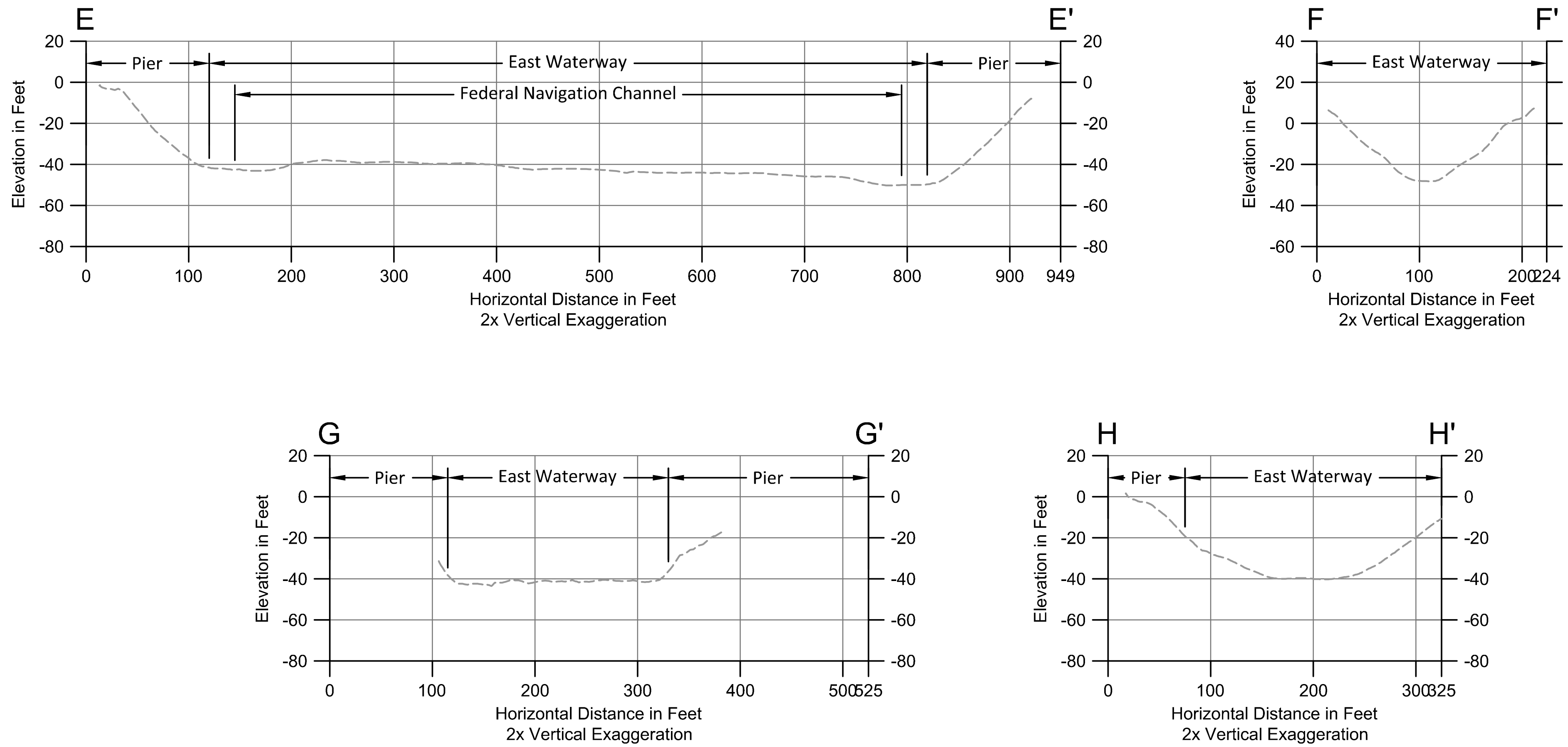
NOTES:
1. Cross-section locations are shown on Figure 2-4a.

LEGEND:

------- Existing Mudline

ANCHOR QEA

Figure 2-4c
Cross-sections
Feasibility Study
East Waterway Study Area



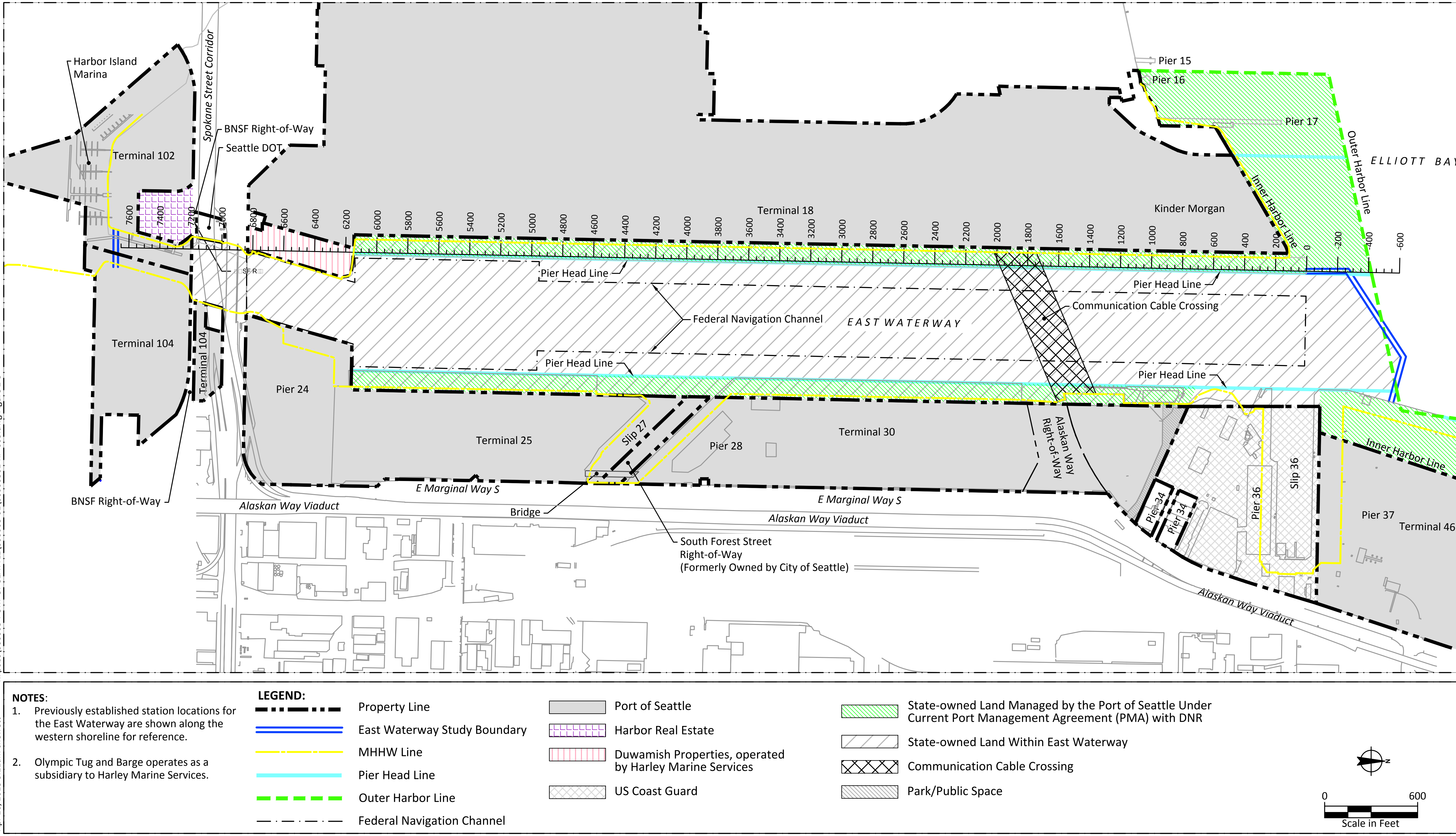
SOURCE: Existing bathymetry survey provided bv David Evans and Associates.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

NOTES:
1. Cross-section locations are shown on Figure 2-4a.

LEGEND:

Existing Mudline

Figure 2-4d
Cross-sections
Feasibility Study
East Waterway Study Area



K:\Jobs\060003-PORT OF SEATTLE\060003-01\06000301-RP-065.dwg Figure 2-5

Apr 16, 2013 8:21am chewett

Figure 2-5
Upland and Aquatic Ownership
Feasibility Study
East Waterway Study Area

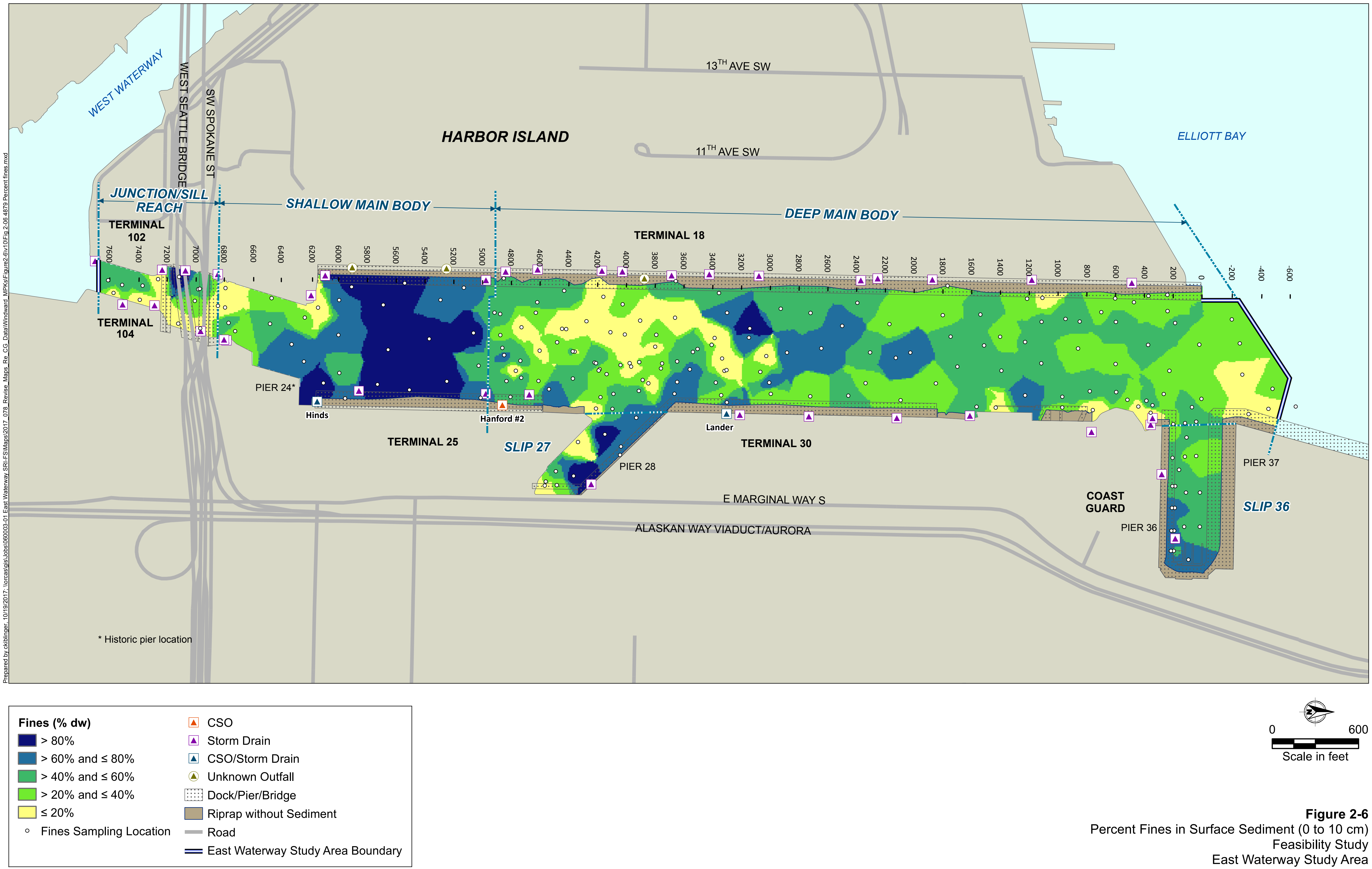


Figure 2-6
Percent Fines in Surface Sediment (0 to 10 cm)
Feasibility Study
East Waterway Study Area

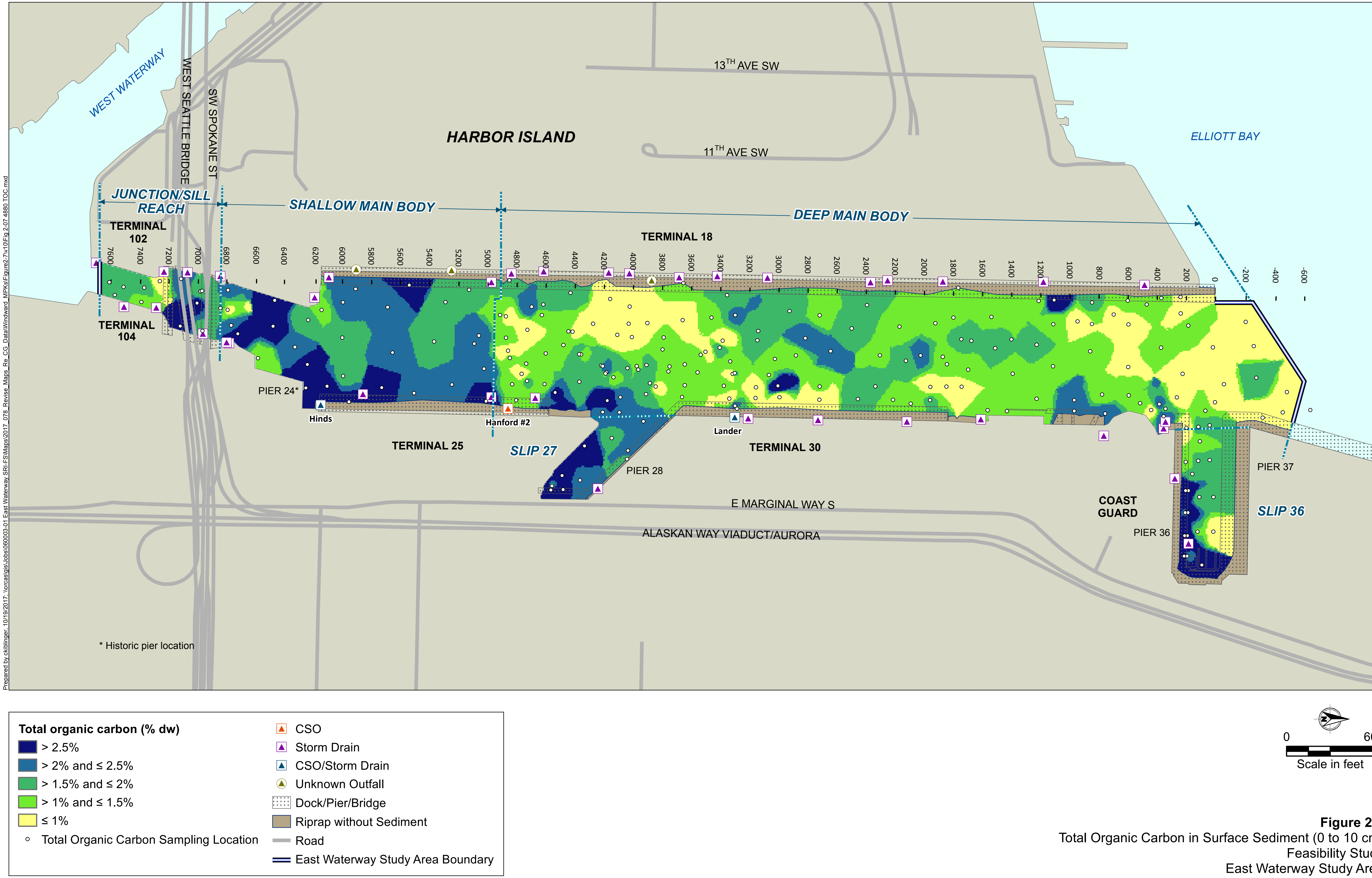
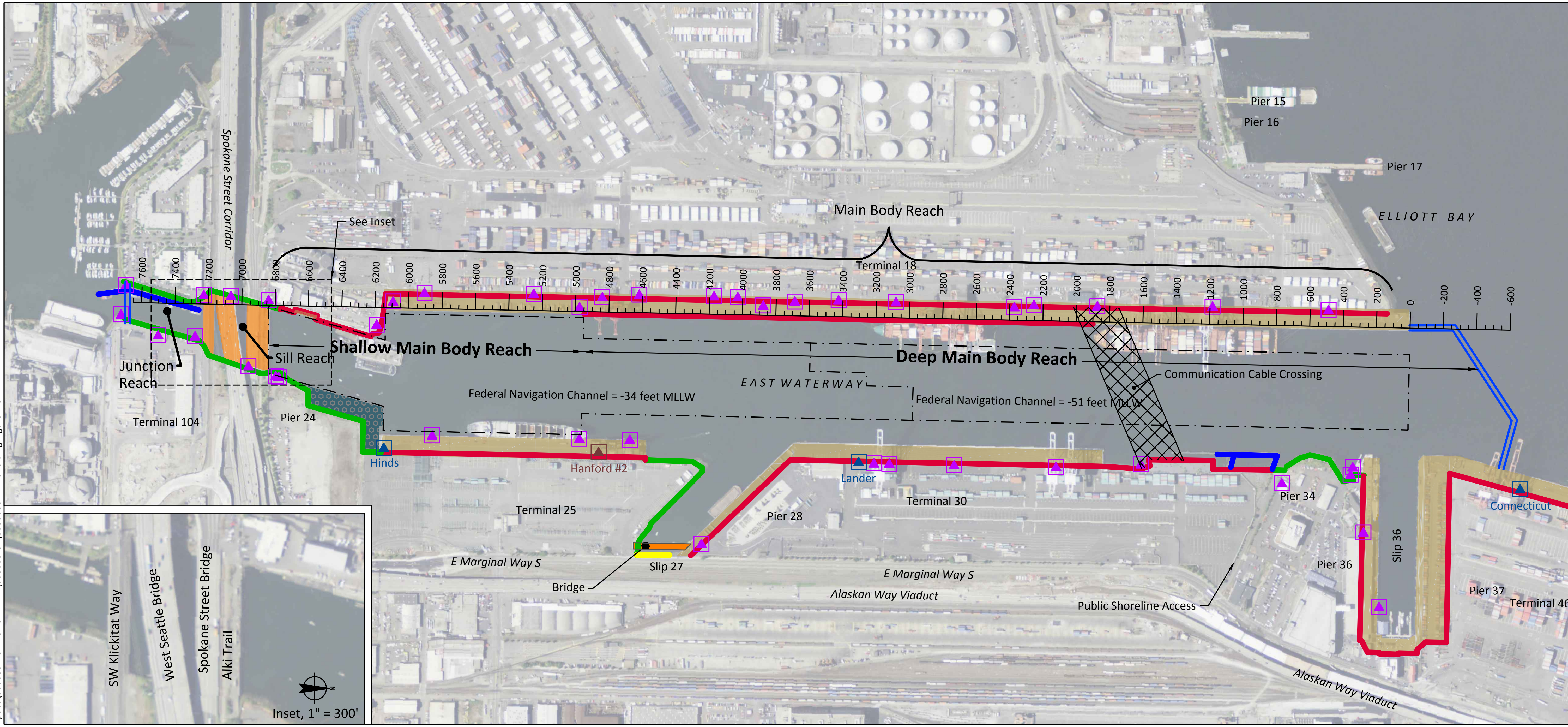


Figure 2-7
Total Organic Carbon in Surface Sediment (0 to 10 cm)
Feasibility Study
East Waterway Study Area

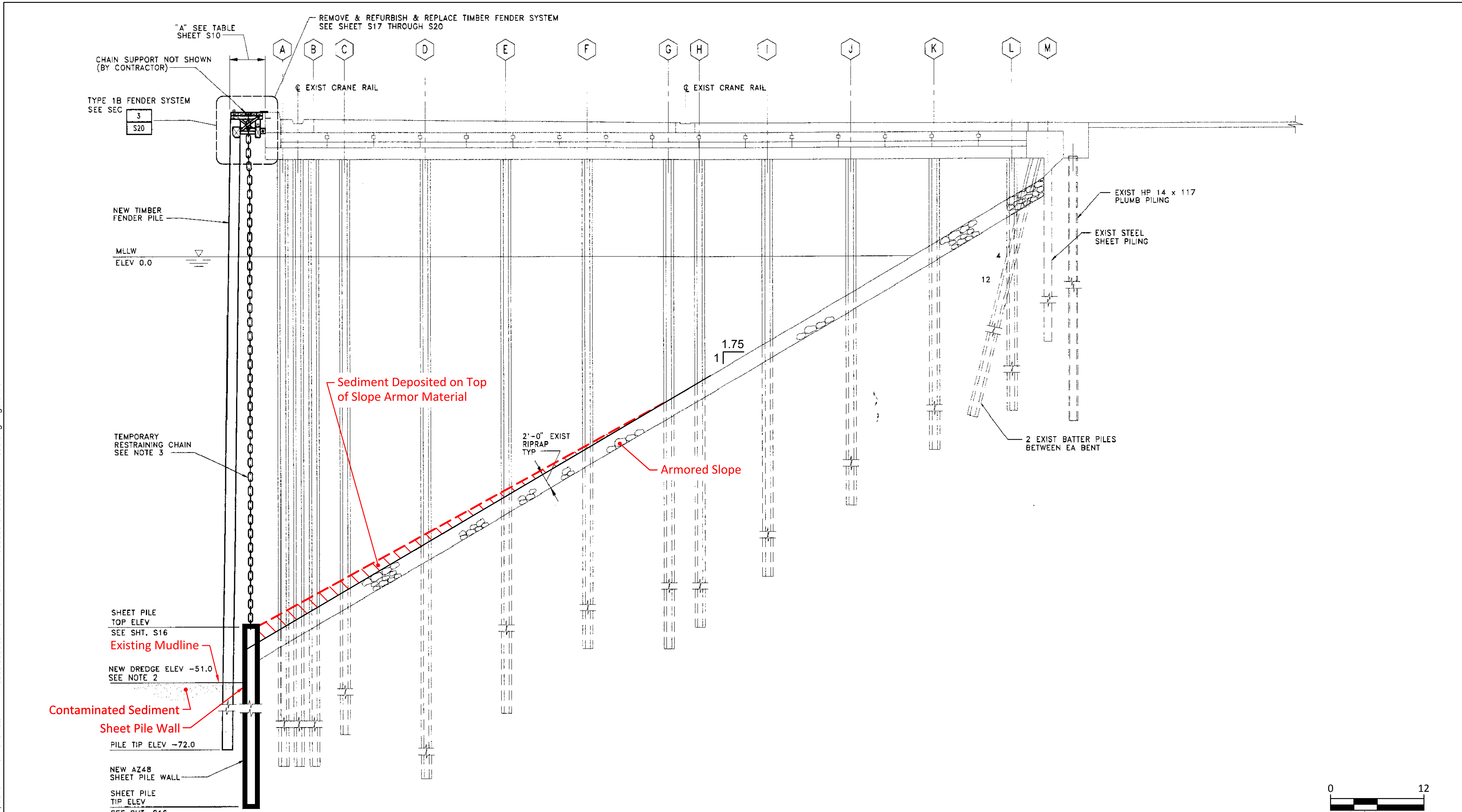


NOTES:
1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. Values along Westside of East Waterway are station reference values.
3. Aerial photo, NAIP 2011.

LEGEND:
- East Waterway Study Boundary
- Federal Navigation Channel
- Piling Field
- Sheetpile Wall
- Exposed Riprap
- Overwater Pier Above Riprap
- Concrete or Timber Bulkhead
- Bridge
- Timber Dock
- CSO
- Storm Drain
- CSO/Storm Drain Location

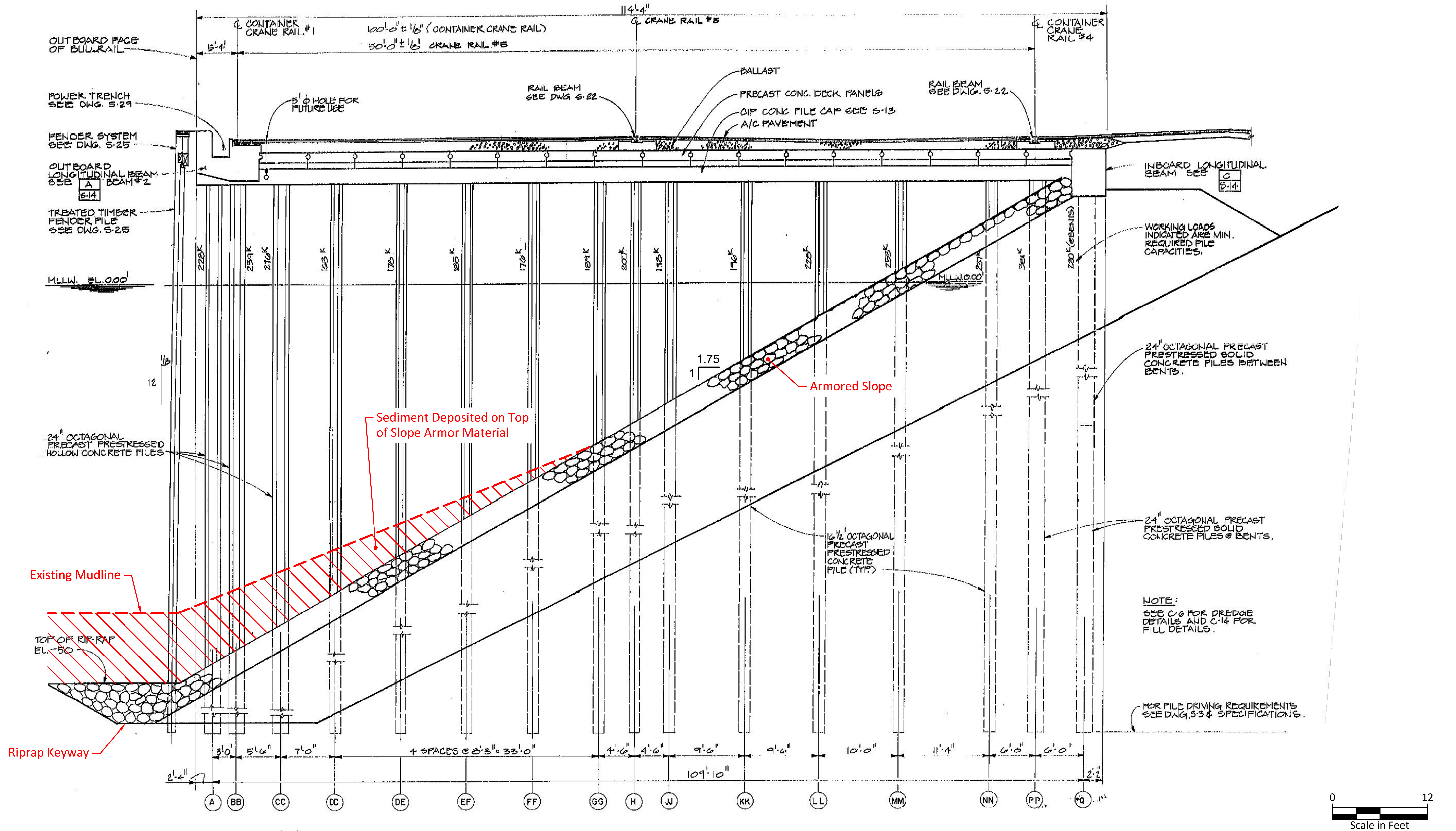
0 600
Scale in Feet

Figure 2-8
Shoreline Conditions and Structures
Feasibility Study
East Waterway Study Area



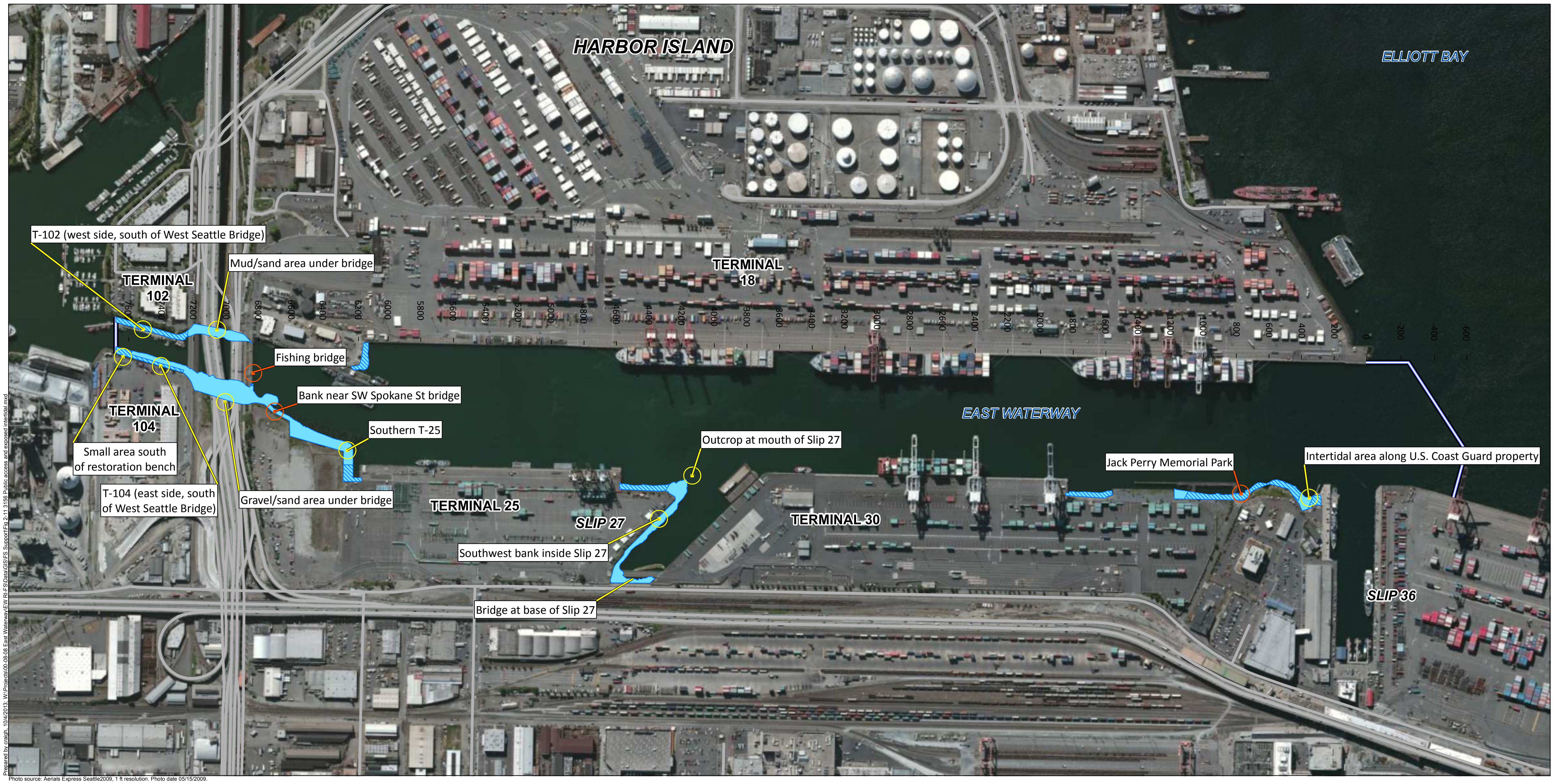
NOTE: Drawing prepared from electronic file by KPFF dated 2/21/2005.

Figure 2-9
Typical Cross Section of Terminal 18 Sheetpile Toe Wall
Feasibility Study
East Waterway Study Area



NOTE: Drawing prepared from electronic file by KPFF dated 7/09/1985.

Figure 2-10
Typical Cross Section of Terminal 25 and 30
Feasibility Study
East Waterway Study Area



- Public Access Location
- Exposed Intertidal Location
- Exposed Intertidal Area
- Fully Armored Exposed Intertidal Area
- East Waterway Study Area

Figure 2-11
Public Access Locations and Exposed Intertidal Areas Within the East Waterway
Feasibility Study
East Waterway Study Area

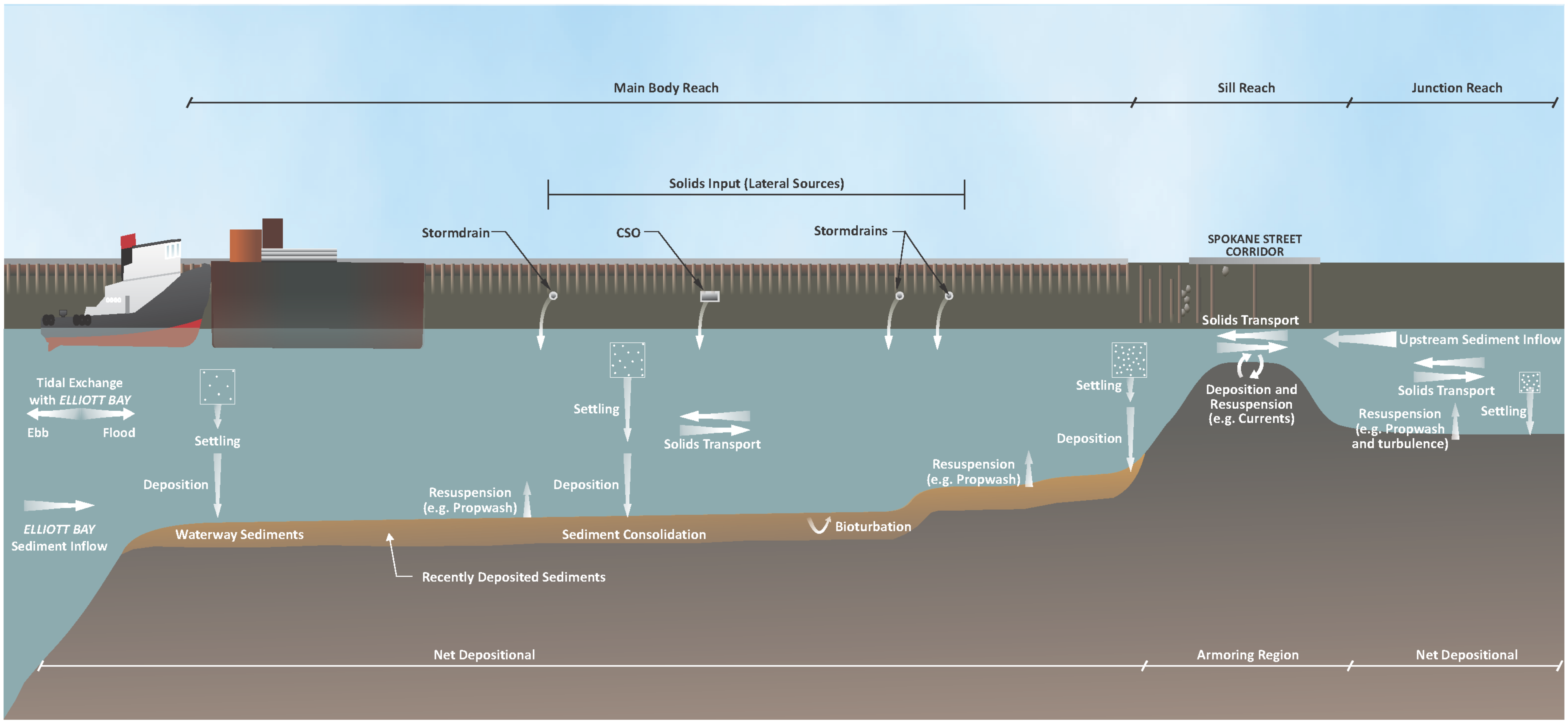


Figure 2-12
Conceptual Summary of Sediment Transport in East Waterway
Feasibility Study
East Waterway Study Area

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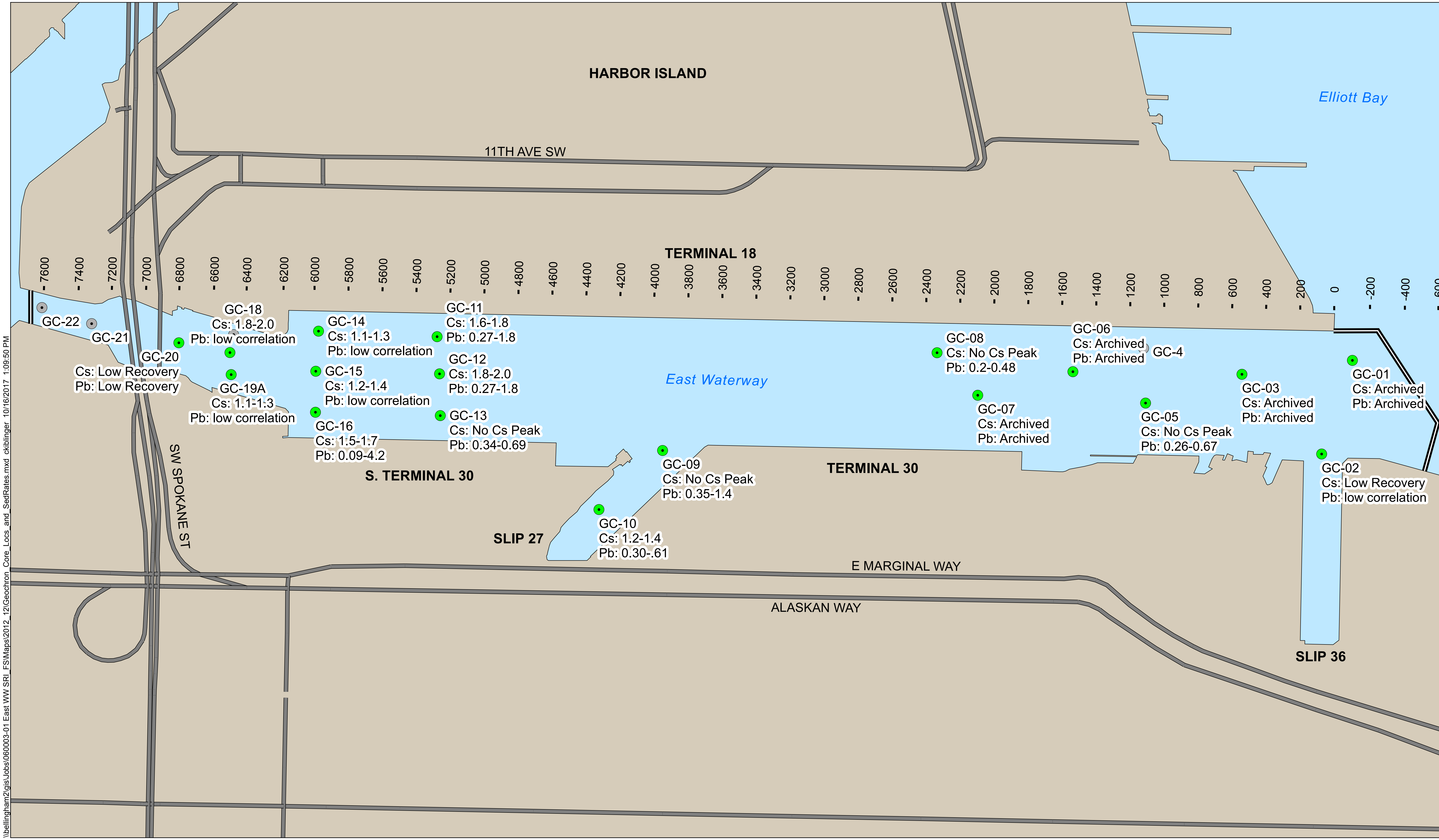
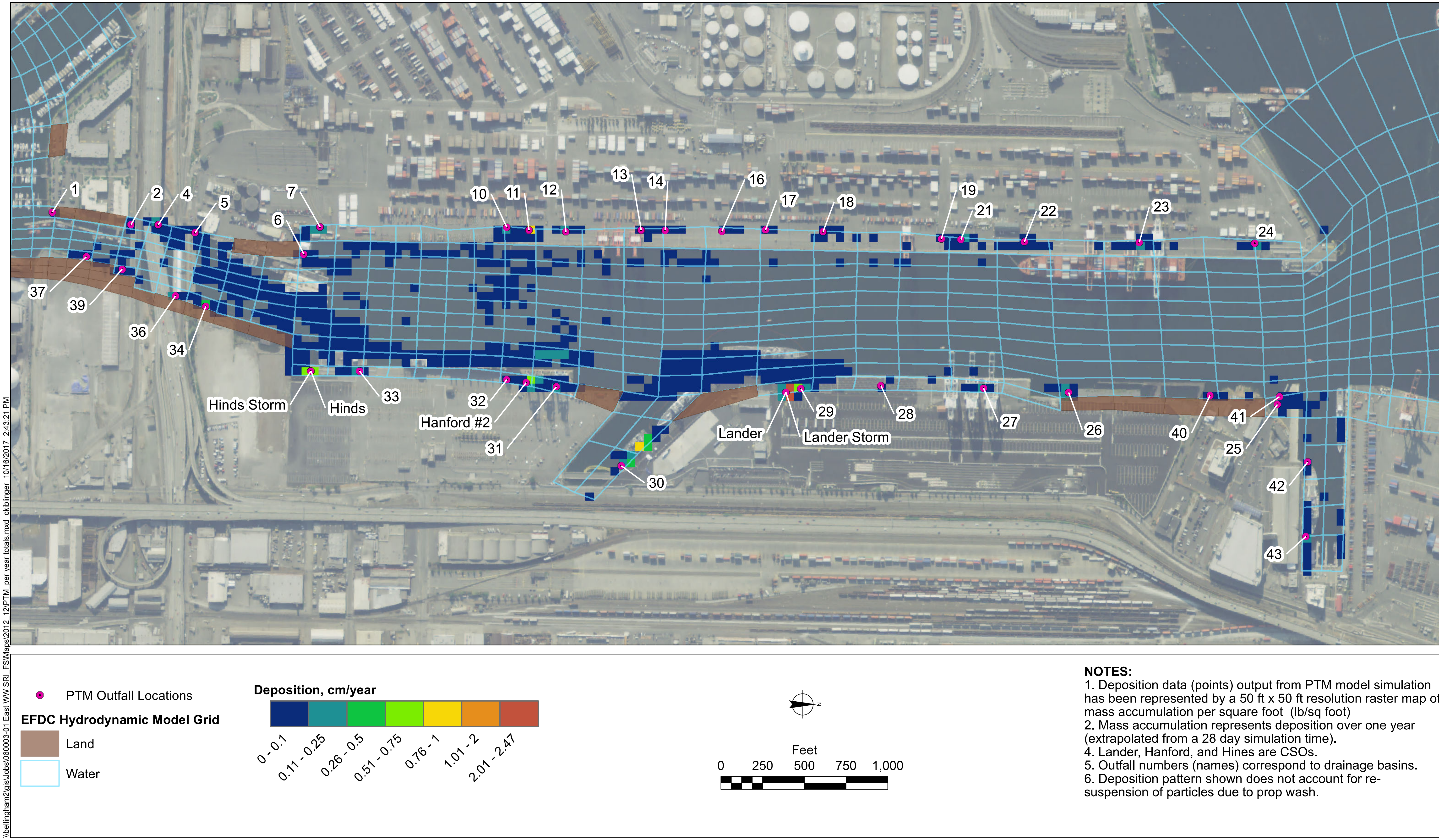


Geochronological Cores - Collected
Geochronological Cores - No Recovery

NOTE:
1. Rates are cm/yr.
2. Presented locations represent accepted at or final attempt.
3. Cs = Cesium - 137
4. Pb = Lead - 210

Figure 2-13
Geochronological Core Locations and Sedimentation Rates
Feasibility Study
East Waterway Study Area



NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation per square foot (lb/sq foot)
2. Mass accumulation represents deposition over one year (extrapolated from a 28 day simulation time).
4. Lander, Hanford, and Hines are CSOs.
5. Outfall numbers (names) correspond to drainage basins.
6. Deposition pattern shown does not account for re-suspension of particles due to prop wash.

Figure 2-14
Predicted Annual Deposition (cm/yr) due to Lateral Loads, Base Case Current Conditions
Feasibility Study
East Waterway Study Area

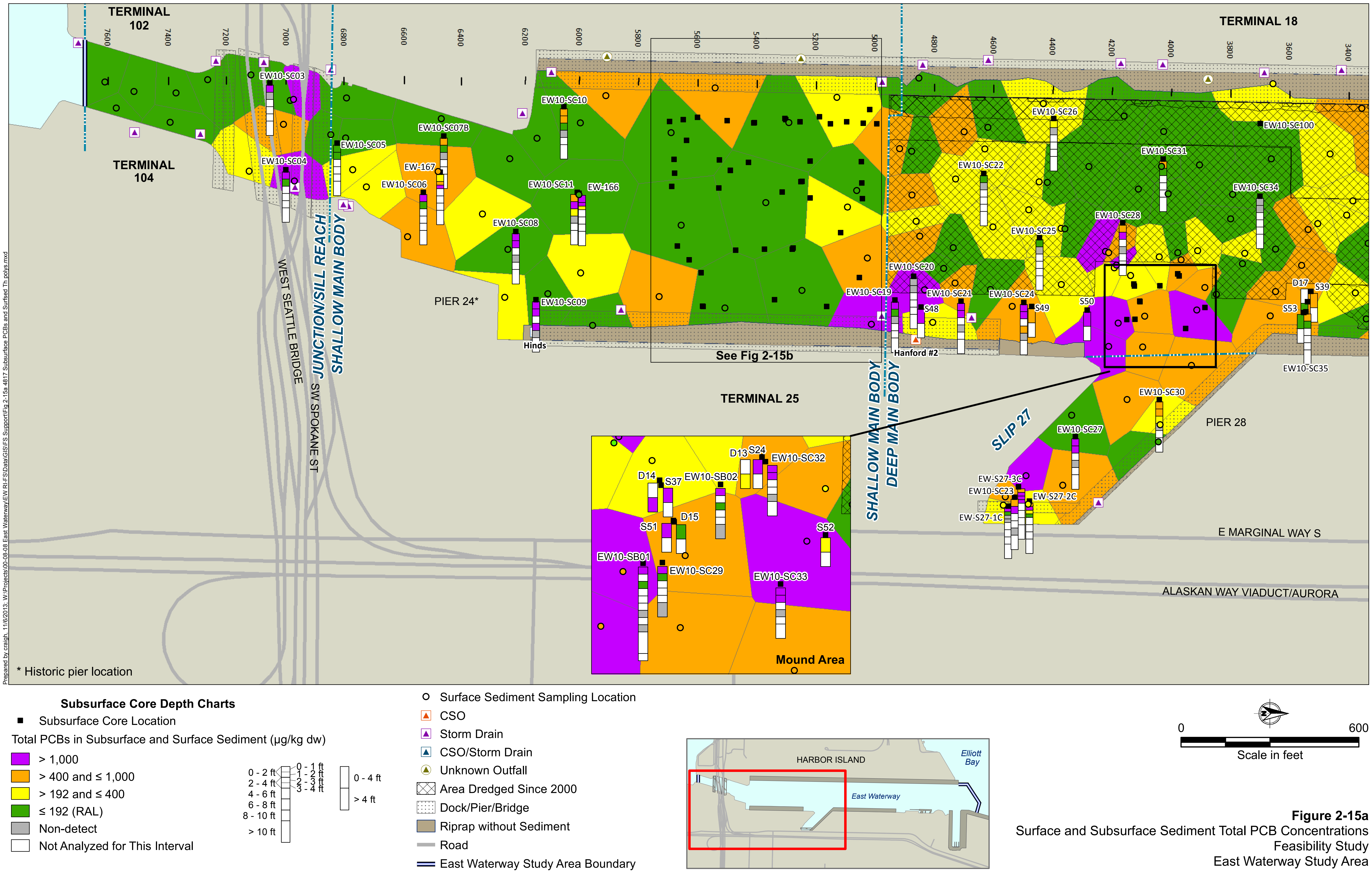
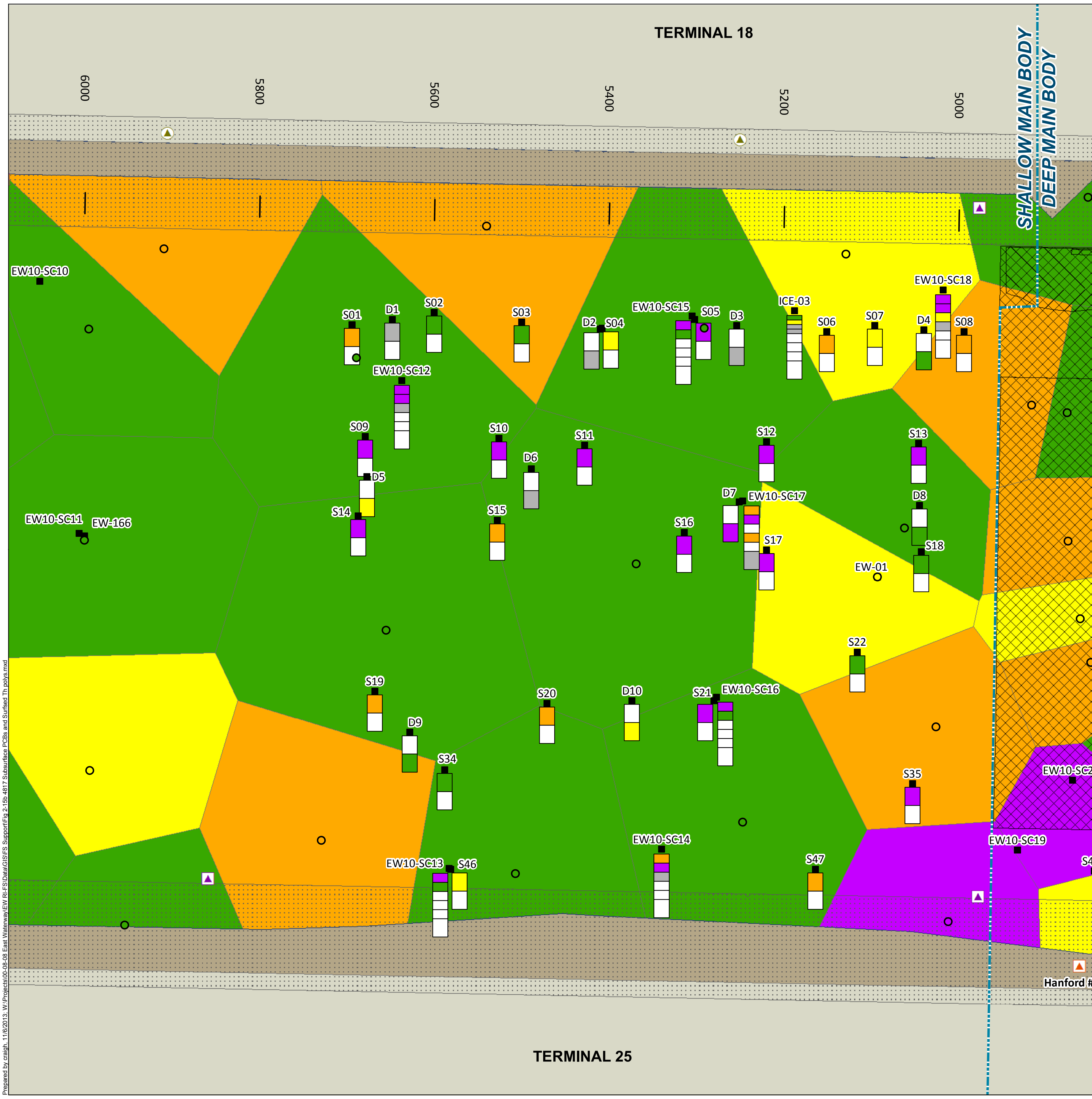
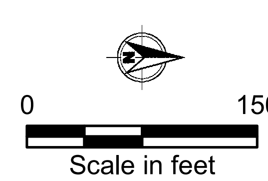


Figure 2-15a
Surface and Subsurface Sediment Total PCB Concentrations
Feasibility Study
East Waterway Study Area



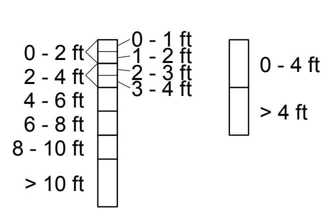


Subsurface Core Depth Charts

■ Subsurface Core Location

Total PCBs in Subsurface and Surface Sediment (µg/kg dw)

- > 1,000
- > 400 and ≤ 1,000
- > 192 and ≤ 400
- ≤ 192 (RAL)
- Non-detect
- Not Analyzed for This Interval



- ○ Surface Sediment Sampling Location
- Area Dredged Since 200
- Dock/Pier/Bridge
- Riprap without Sediment
- CSO
- CSO/Storm Drain
- Storm Drain
- Unknown
- East Waterway Study Area Boundary

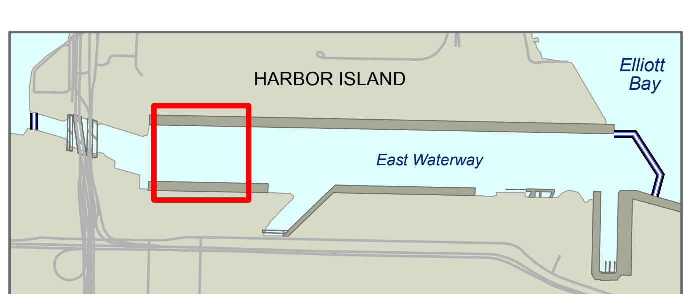
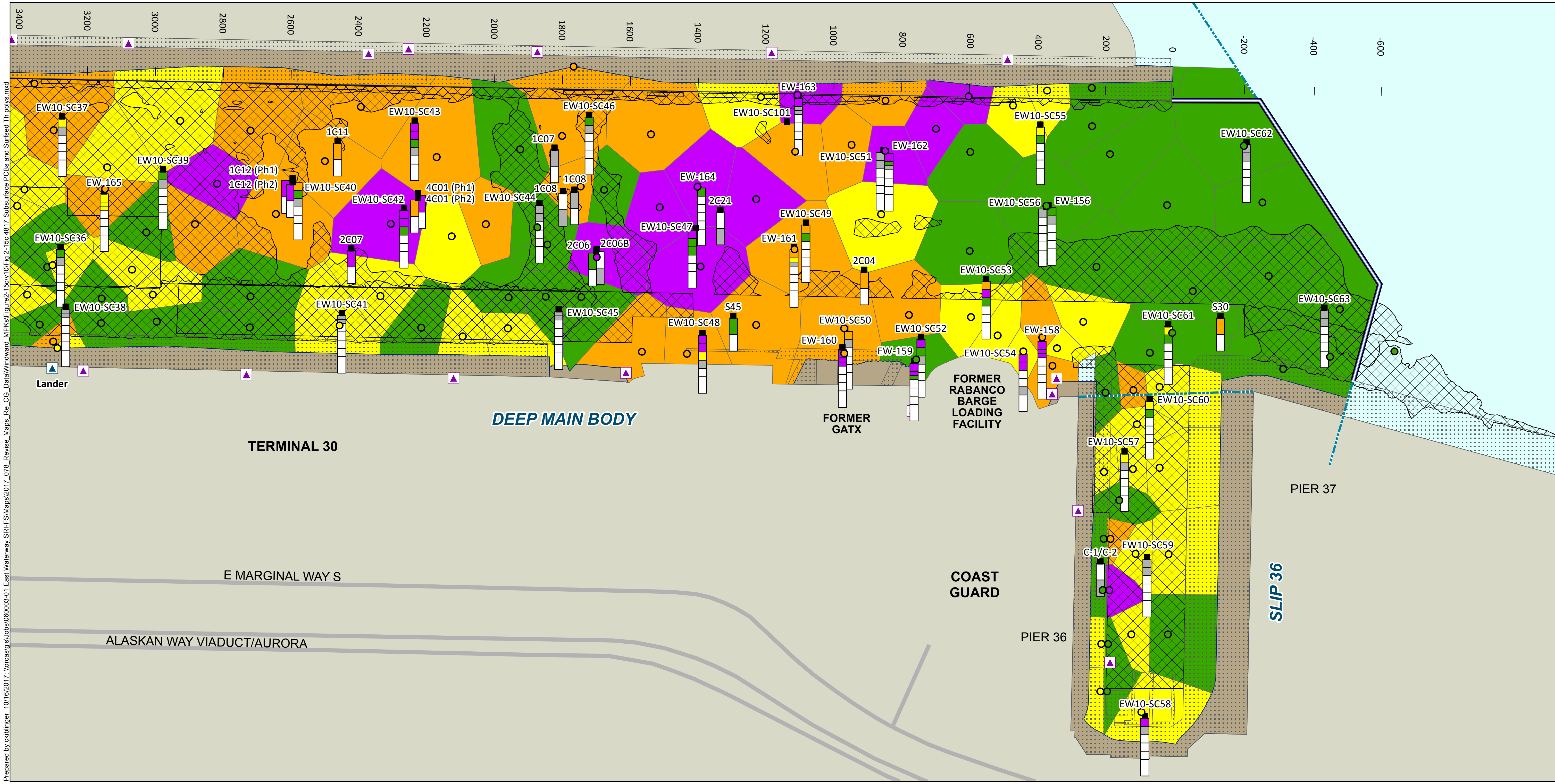


Figure 2-15b
Surface and Subsurface Sediment
Total PCB Concentrations
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

■ Subsurface Core Location

Total PCBs in Subsurface and Surface Sediment (µg/kg dw)

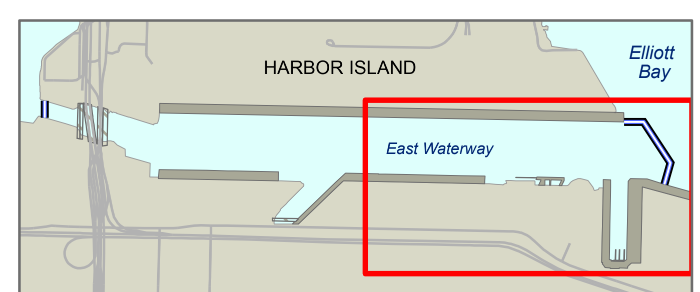
- > 1,000
- > 400 and ≤ 1,000
- > 192 and ≤ 400
- ≤ 192 (RAL)
- Non-detect
- Not Analyzed for This Interval

0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

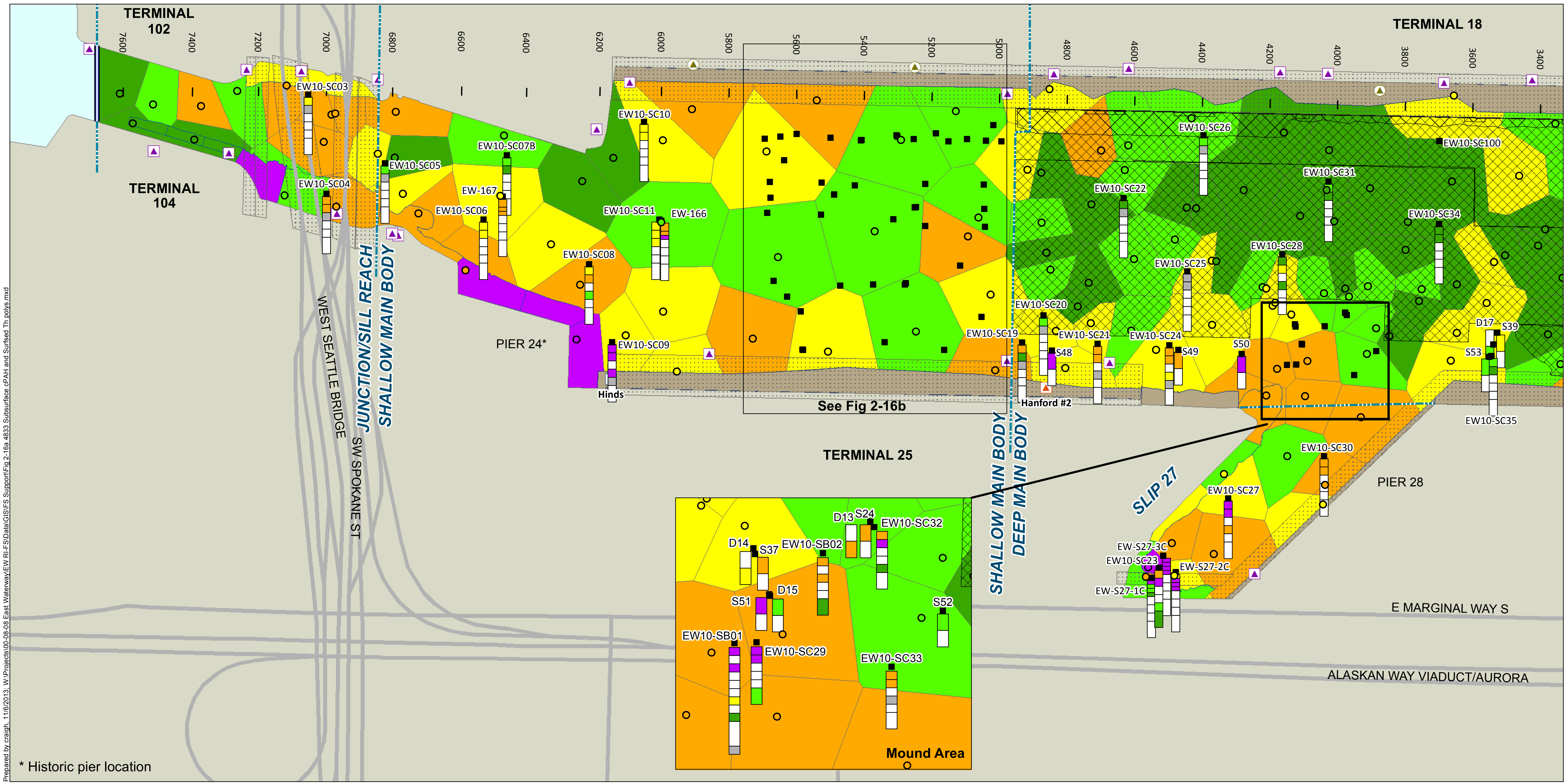
0 - 4 ft, > 4 ft

- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary



0 600
Scale in feet

Figure 2-15c
Surface and Subsurface Sediment Total PCB Concentrations
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

■ Subsurface Core Location

cPAH in Subsurface and Surface Sediment (µg TEQ/kg dw)[a]

- > 1,200 (> 95th percentile)
- > 480 and ≤ 1,200 (≤ 95th percentile)
- > 220 and ≤ 480 (≤ 75th percentile)
- > 95 and ≤ 220 (≤ 50th percentile)
- ≤ 95 (≤ 25th percentile)
- Non-detect
- Not Analyzed for This Interval

0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft; 0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft; 0 - 4 ft, > 4 ft

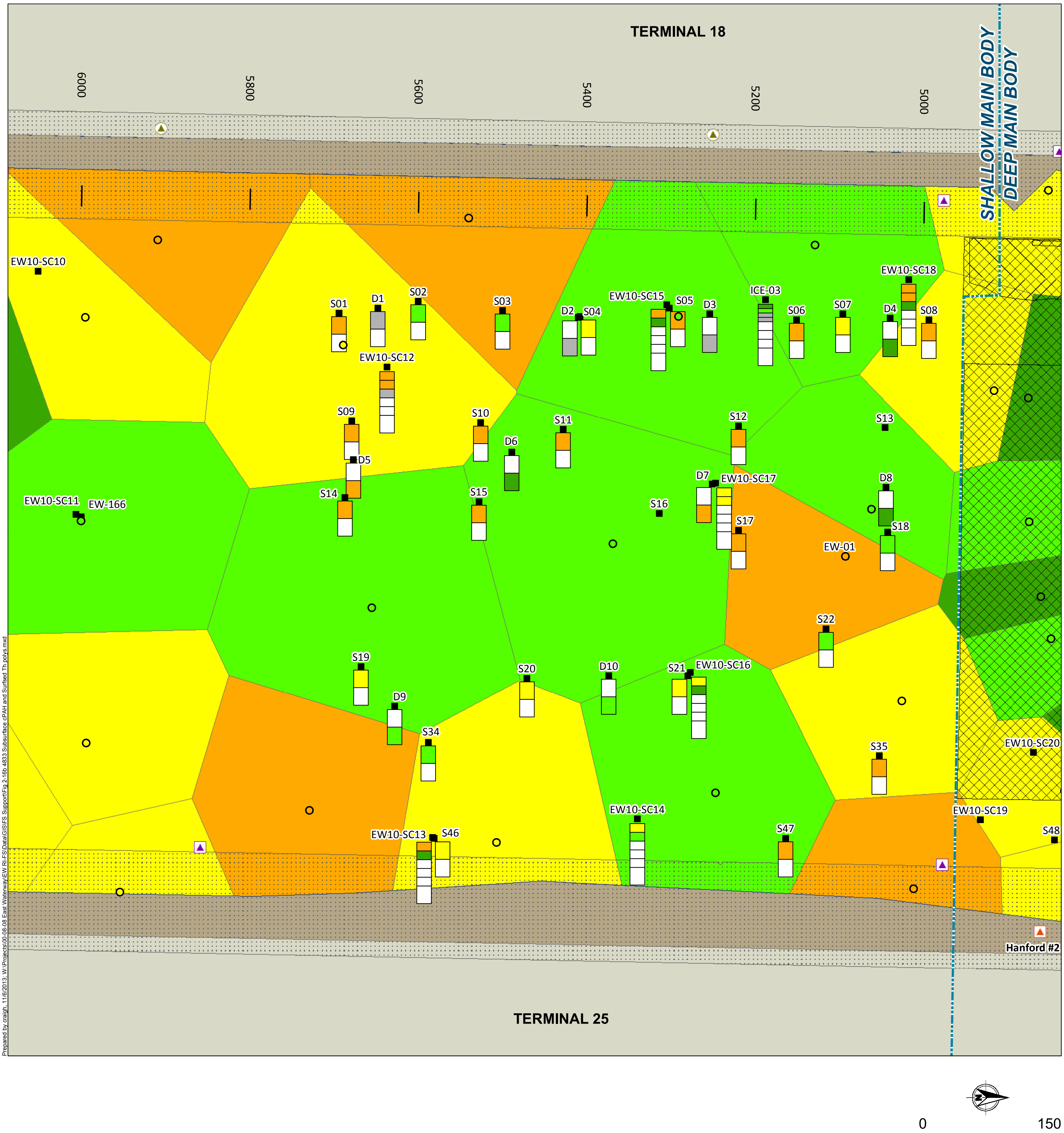
- ○ Surface Sediment Sampling Location
- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary

HARBOR ISLAND
Elliott Bay
East Waterway

0 600
Scale in feet

[a] Gray border = surface sediment Thiessen polygon extrapolation; blue border = MIS composite sample extrapolation.
The percentiles are all numeric percentiles of the surface sediment dataset.

Figure 2-16a
Surface and Subsurface Sediment cPAH Concentrations
Feasibility Study
East Waterway Study Area

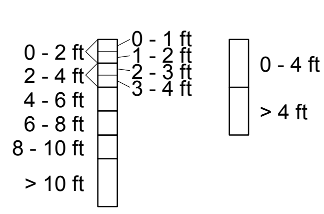


Subsurface Core Depth Charts

■ Subsurface Core Location

cPAH in Subsurface and Surface Sediment (µg TEQ/kg dw)

- > 1,200 (> 95th percentile)
- > 480 and ≤ 1,200 (≤ 95th percentile)
- > 220 and ≤ 480 (≤ 75th percentile)
- > 95 and ≤ 220 (≤ 50th percentile)
- ≤ 95 (≤ 25th percentile)
- Non-detect
- Not Analyzed for This Interval



The percentiles are all numeric percentiles of the surface sediment dataset.

- ○ Surface Sediment Sampling Location
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- CSO
- CSO/Storm Drain
- Storm Drain
- Unknown
- East Waterway Study Area Boundary

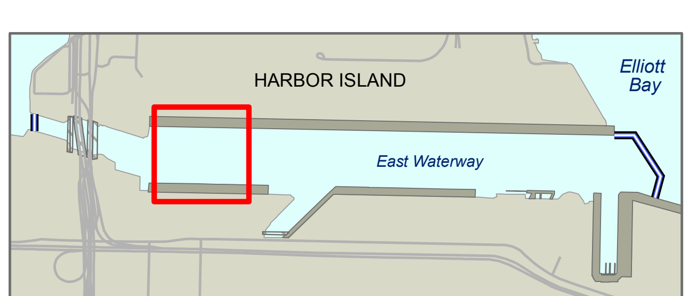
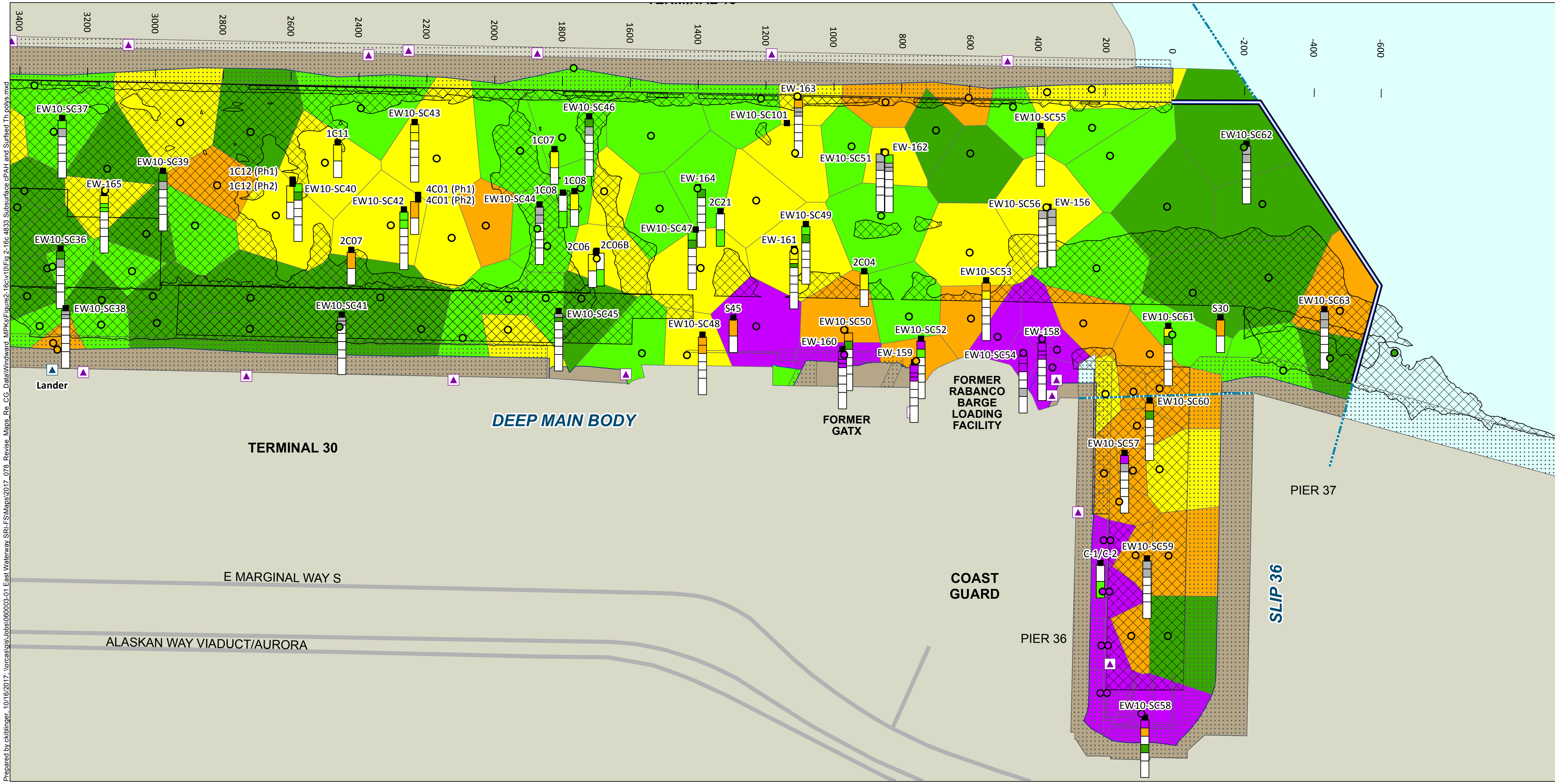


Figure 2-16b
Surface and Subsurface Sediment
cPAH Concentrations
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

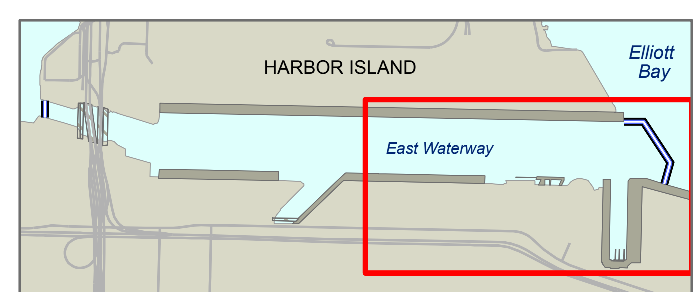
■ Subsurface Core Location

cPAH in Subsurface and Surface Sediment (μg TEQ/kg dw)[a]

- > 1,200 (> 95th percentile)
- > 480 and ≤ 1,200 (≤ 95th percentile)
- > 220 and ≤ 480 (≤ 75th percentile)
- > 95 and ≤ 220 (≤ 50th percentile)
- ≤ 95 (≤ 25th percentile)
- Non-detect
- Not Analyzed for This Interval

0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft; 0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft; 0 - 4 ft, > 4 ft

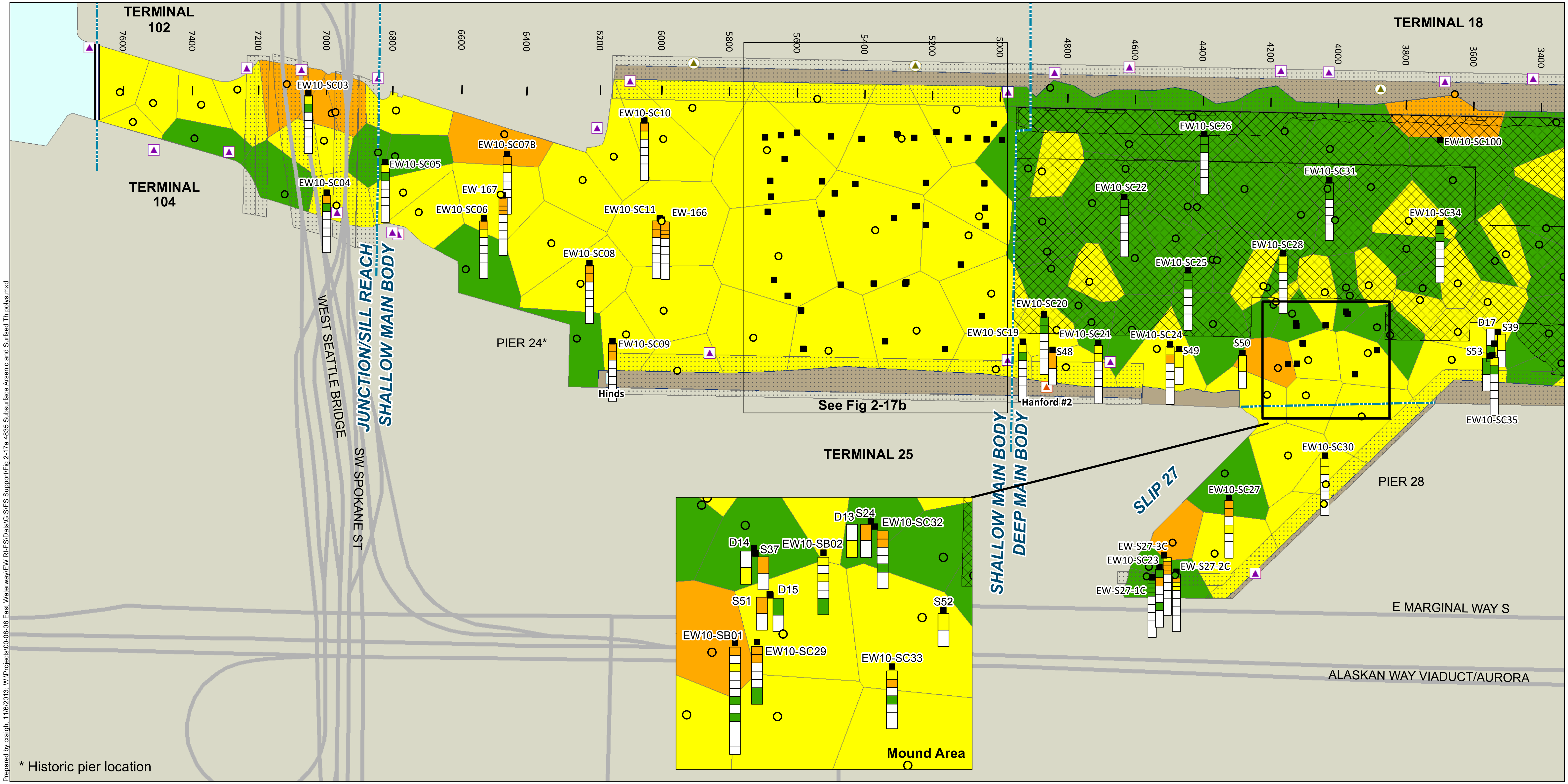
- Surface Sediment Sampling Location
- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary



0 600
Scale in feet

[a] Gray border = surface sediment Thiessen polygon extrapolation; blue border = MIS composite sample extrapolation.

Figure 2-16c
Surface and Subsurface Sediment cPAH Concentrations
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

■ Subsurface Core Location

Arsenic in Subsurface and Surface Sediment (mg/kg dw)

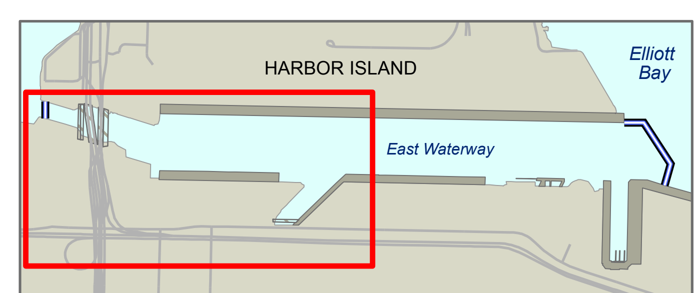
- > 57 (> SQS)
- > 15 and ≤ 57 (≤ SQS)
- > 7.0 and ≤ 15
- ≤ 7.0
- Non-detect
- Not Analyzed for This Interval

0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

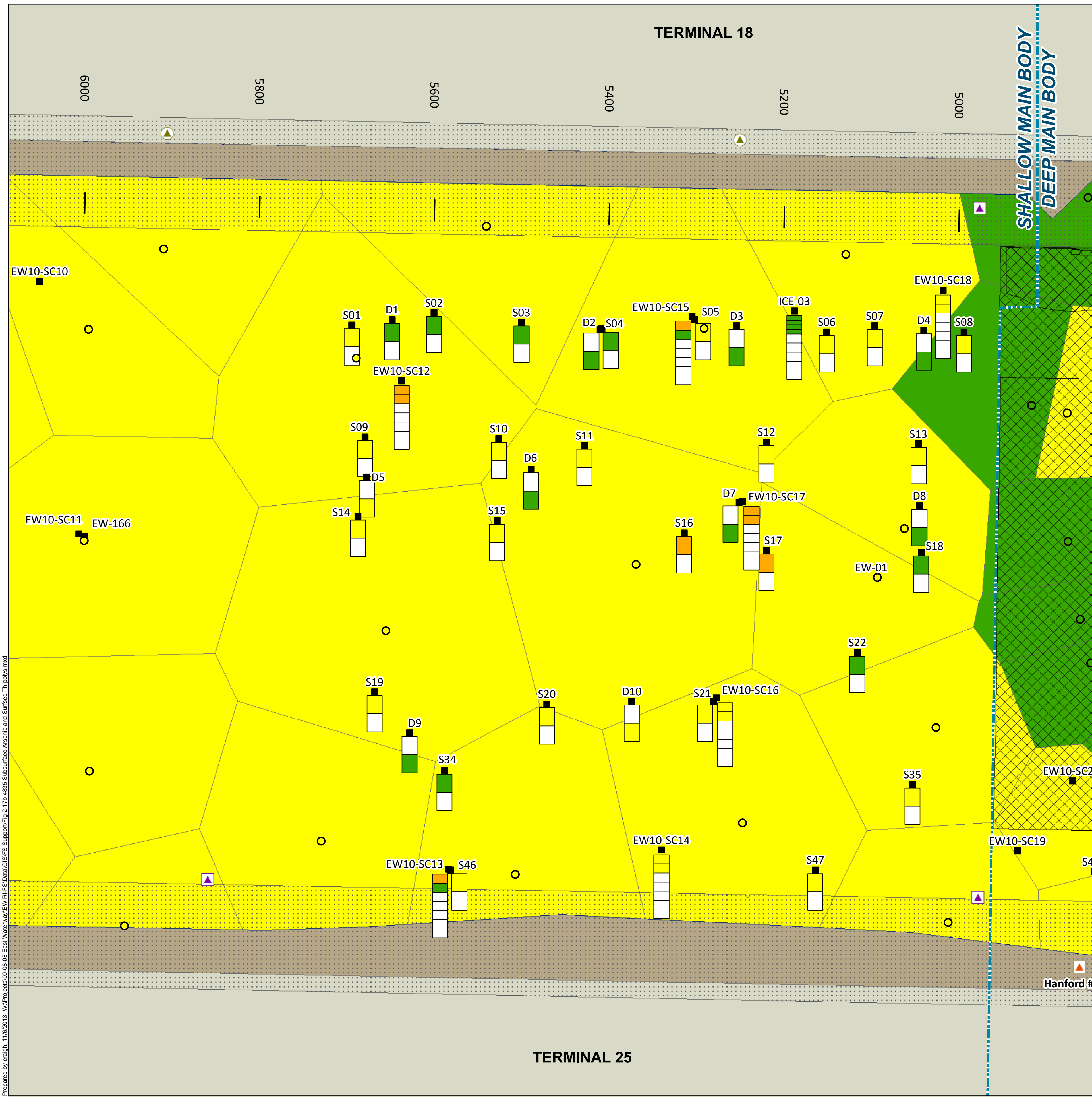
0 - 4 ft, > 4 ft

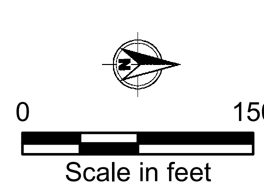
- Surface Sediment Sampling Location
- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary



0 600
Scale in feet

Figure 2-17a
Surface and Subsurface Sediment Arsenic Concentrations
Feasibility Study
East Waterway Study Area





Subsurface Core Depth Charts

■ Subsurface Core Location

Arsenic in Subsurface and Surface Sediment (mg/kg dw)

- > 57 (> SQS)
- > 15 and ≤ 57 (≤ SQS)
- > 7.0 and ≤ 15
- ≤ 7.0
- Non-detect
- Not Analyzed for This Interval

0 - 2 ft, 0 - 1 ft, 1 - 2 ft, 2 - 4 ft, 2 - 3 ft, 3 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 4 ft, > 4 ft

- Surface Sediment Sampling Location
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- CSO
- CSO/Storm Drain
- Storm Drain
- Unknown
- East Waterway Study Area Boundary

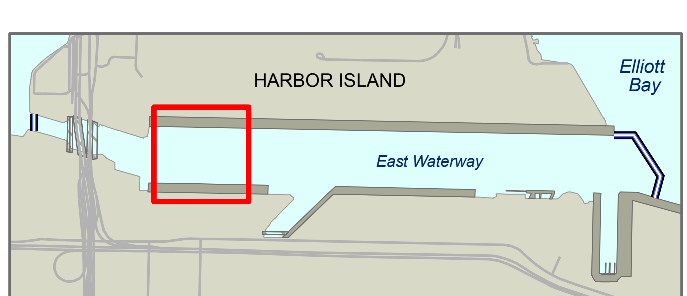


Figure 2-17b
Surface and Subsurface Sediment
Arsenic Concentrations
Feasibility Study
East Waterway Study Area

Prepared by craigh, 11/6/2013; W:\Projects\00-08-08 East Waterway\EW RI-FS\Data\GIS\FS Support\Fig 2-17b 4835 Subsurface Arsenic and Surfsed Th polys.mxd

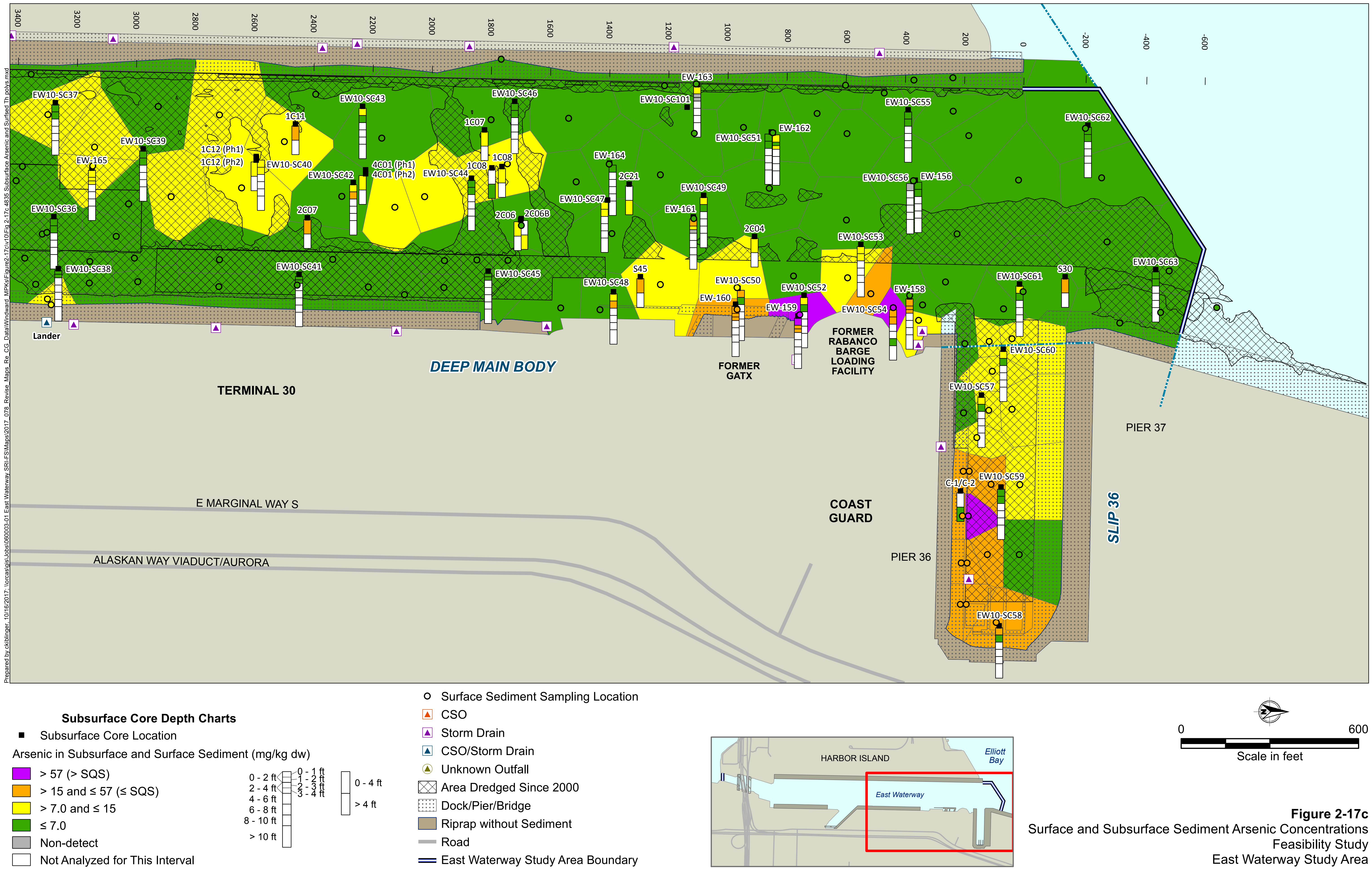
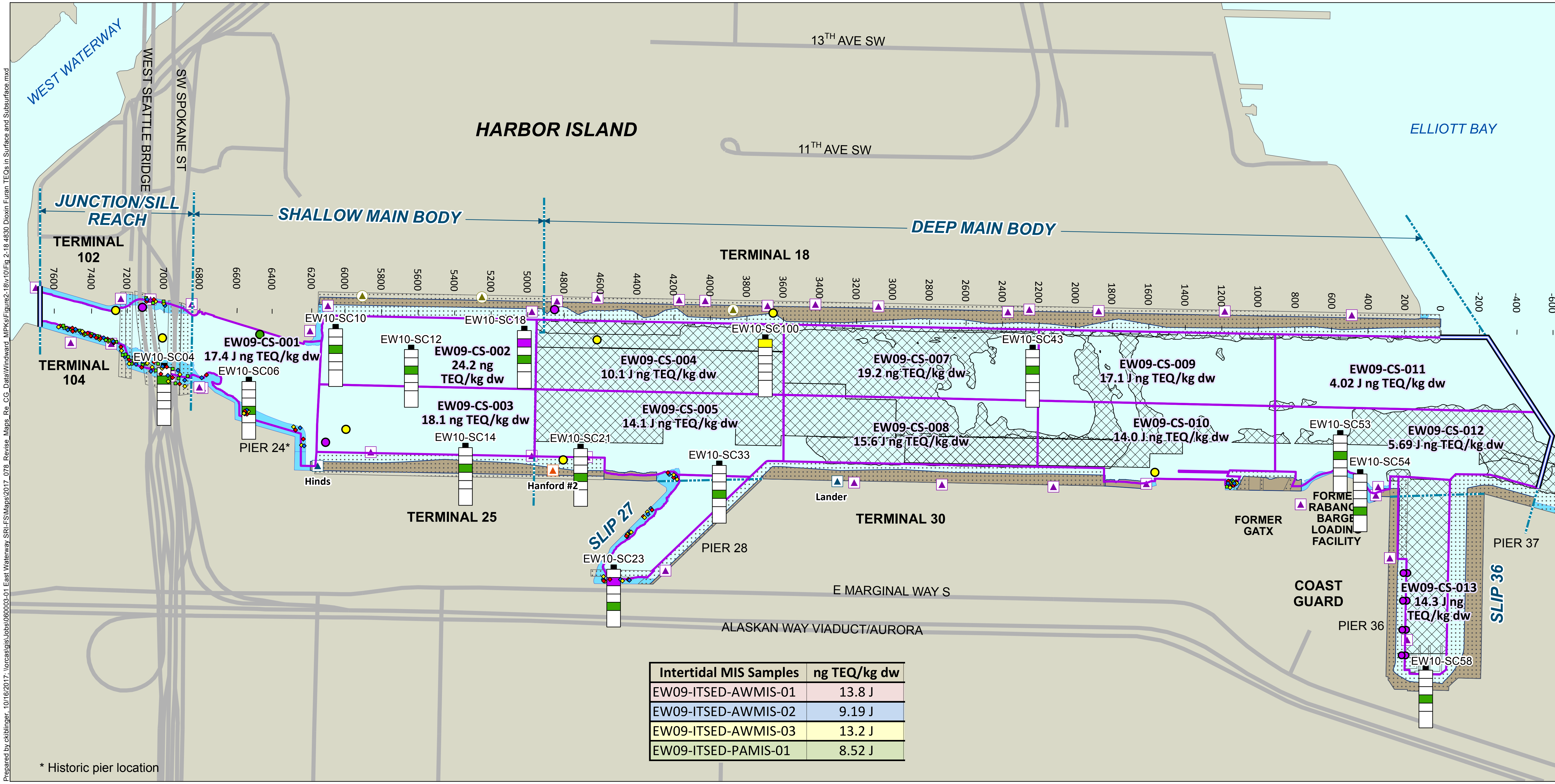


Figure 2-17c
Surface and Subsurface Sediment Arsenic Concentrations
Feasibility Study
East Waterway Study Area



Intertidal MIS Samples	ng TEQ/kg dw
EW09-ITSED-AWMIS-01	13.8 J
EW09-ITSED-AWMIS-02	9.19 J
EW09-ITSED-AWMIS-03	13.2 J
EW09-ITSED-PAMIS-01	8.52 J

Subsurface Core Depth Charts

Subsurface Core Location

Dioxin and Furan TEQs in Subsurface and Surface Sediment (ng TEQ/kg dw)

- > 25 (RAL)
- > 10 and ≤ 25
- ≤ 10
- Not Analyzed for This Interval

0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft; 0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

Grab Sample Location

Subtidal Composite Area Boundary

Multi-Increment Sampling (MIS) Composite Locations

- EW09-ITSED-AWMIS-01
- EW09-ITSED-AWMIS-02
- EW09-ITSED-AWMIS-03
- EW09-ITSED-PAMIS-01

Intertidal Zone

Riprap without Sediment

CSO

Storm Drain

CSO/Storm Drain

Unknown Outfall

Area Dredged Since 2000

Dock/Pier/Bridge

Road

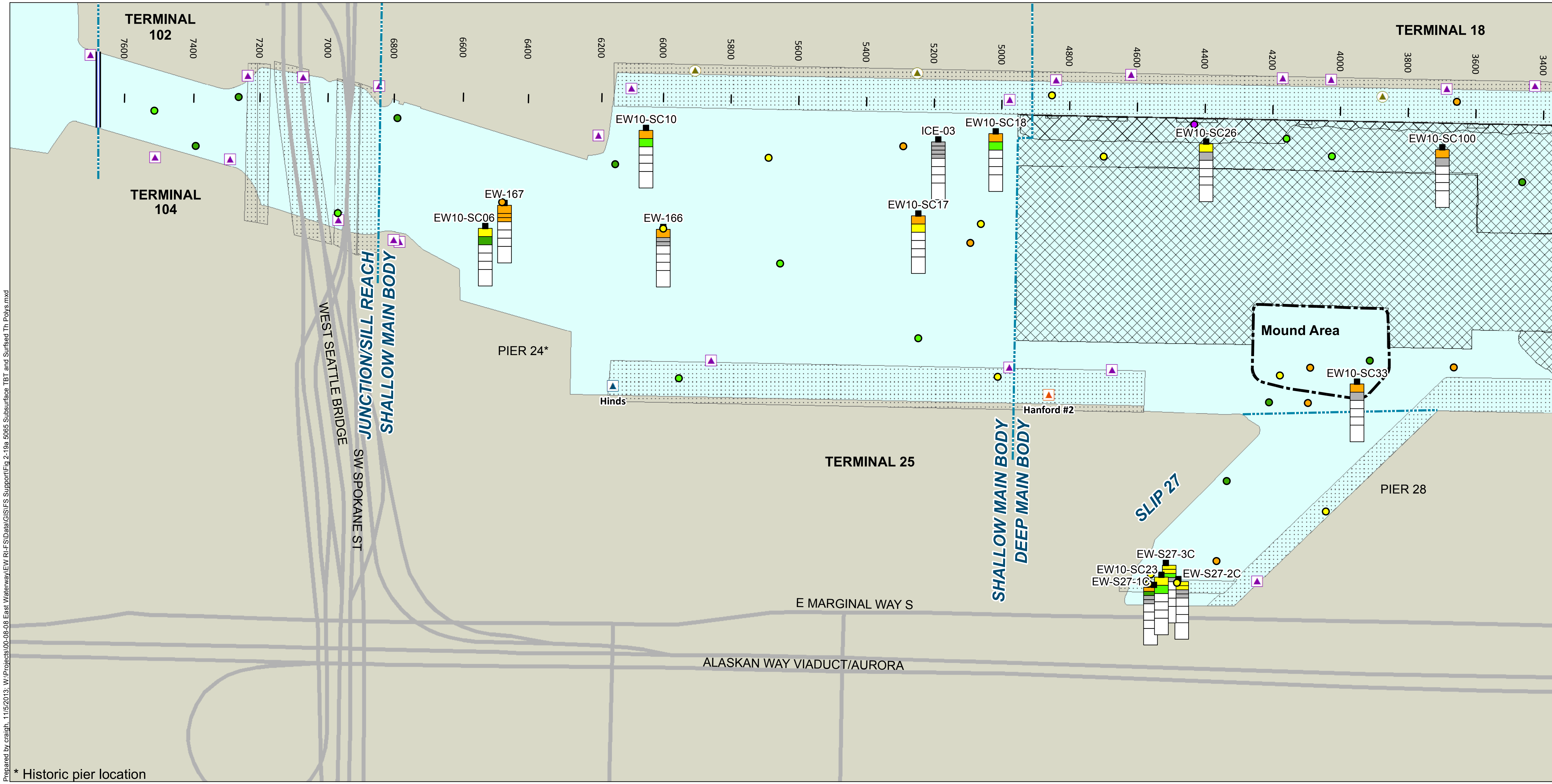
East Waterway Study Area Boundary

0 600

Scale in feet

Prepared by ckiblinger, 10/16/2017, \\orcas\gis\Jobs\060003-01 East Waterway SRI-FS\Maps\2017_07\8_Revise_Maps_Re_CG_Data\Windward_MPKs\Figure2-18\v10\Fig 2-18 4830 Dioxin Furan TEQs in Surface and Subsurface.mxd

Figure 2-18
Dioxin and Furan TEQ Values for Surface and Subsurface Sediment
Feasibility Study
East Waterway Study Area



Prepared by craigh, 11/5/2013; W:\Projects\00-08 East Waterway\EW RI-FS\Data\GIS\FS Support\Fig 2-19a 5065 Subsurface TBT and Surfsed Th Polys.mxd

Subsurface Core Depth Charts

- ■ Subsurface Core Location

TBT in Subsurface and Surface Sediment (µg/kg dw)

- > 560 (> 95th percentile)
- > 79 and ≤ 560 (≤ 95th percentile)
- > 31 and ≤ 79 (≤ 75th percentile)
- > 10 and ≤ 31 (≤ 50th percentile)
- ≤ 10 (≤ 25th percentile)
- Non-detect
- Not Analyzed for This Interval

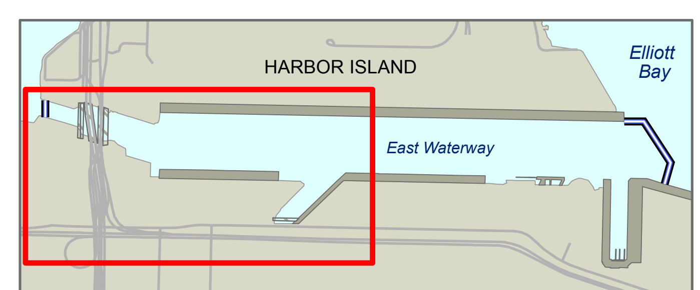
0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

0 - 4 ft, > 4 ft

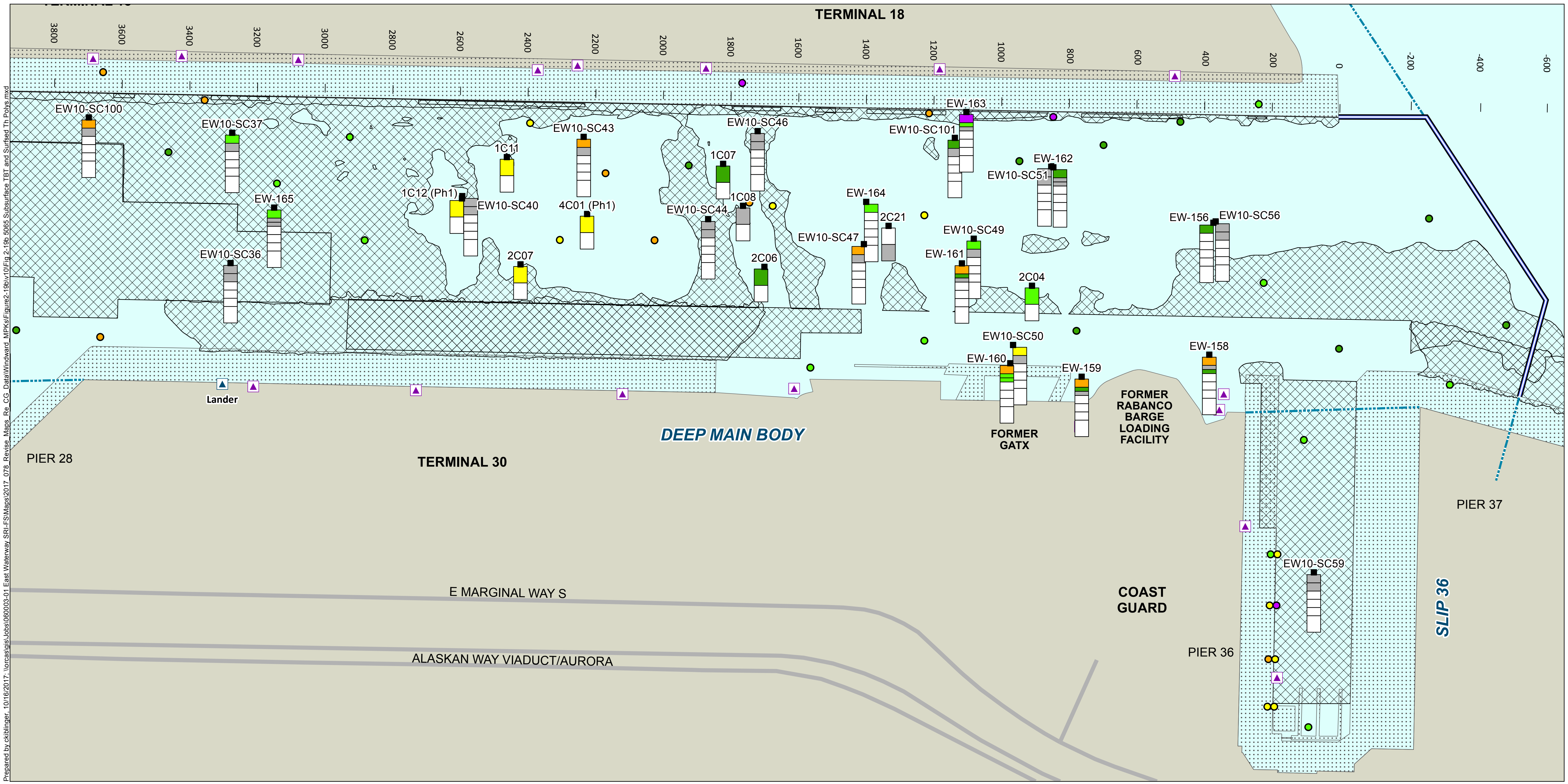
The percentiles are all numeric percentiles of the surface sediment dataset.

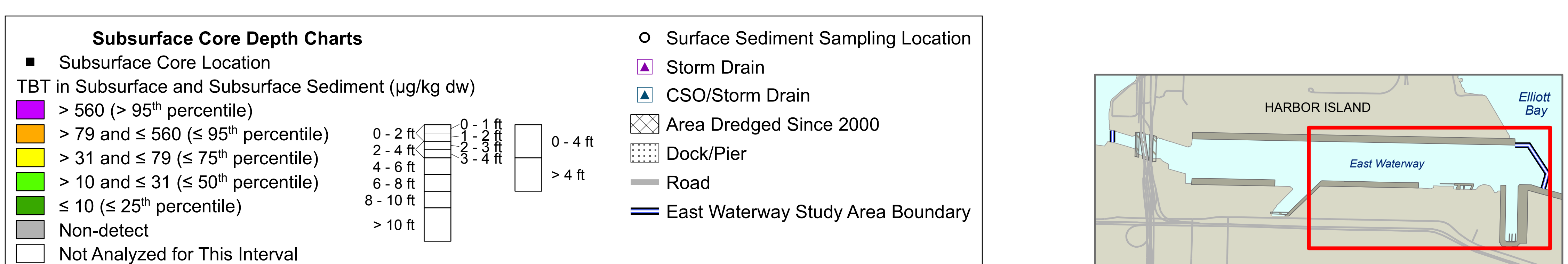
- ○ Surface Sediment Sampling Location
- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Road
- East Waterway Study Area Boundary



0 600
Scale in feet

Figure 2-19a
Surface and Subsurface Sediment TBT Concentrations
Feasibility Study
East Waterway Study Area





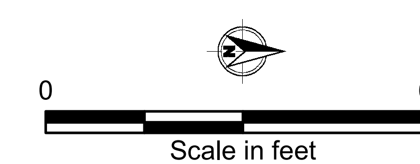
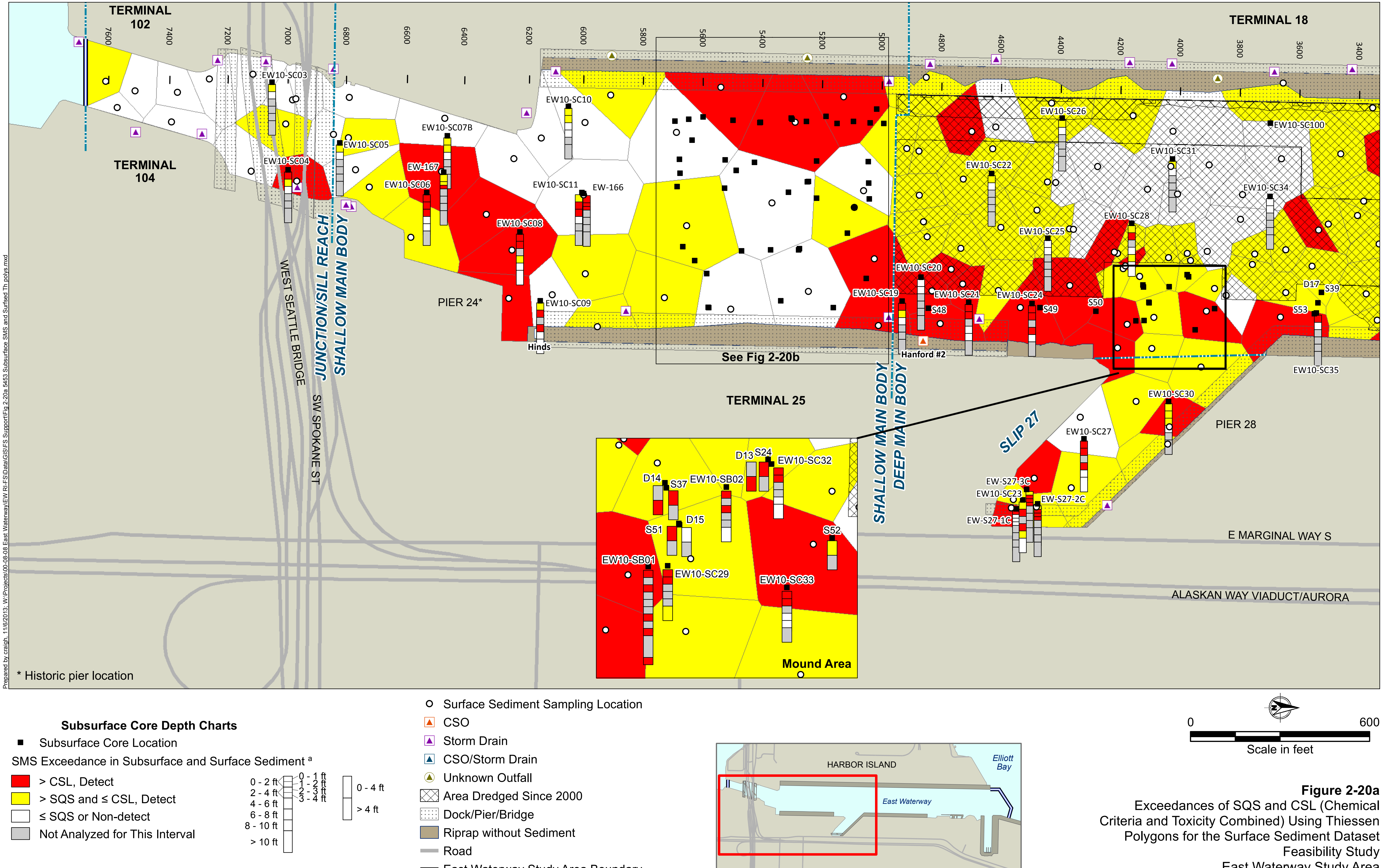
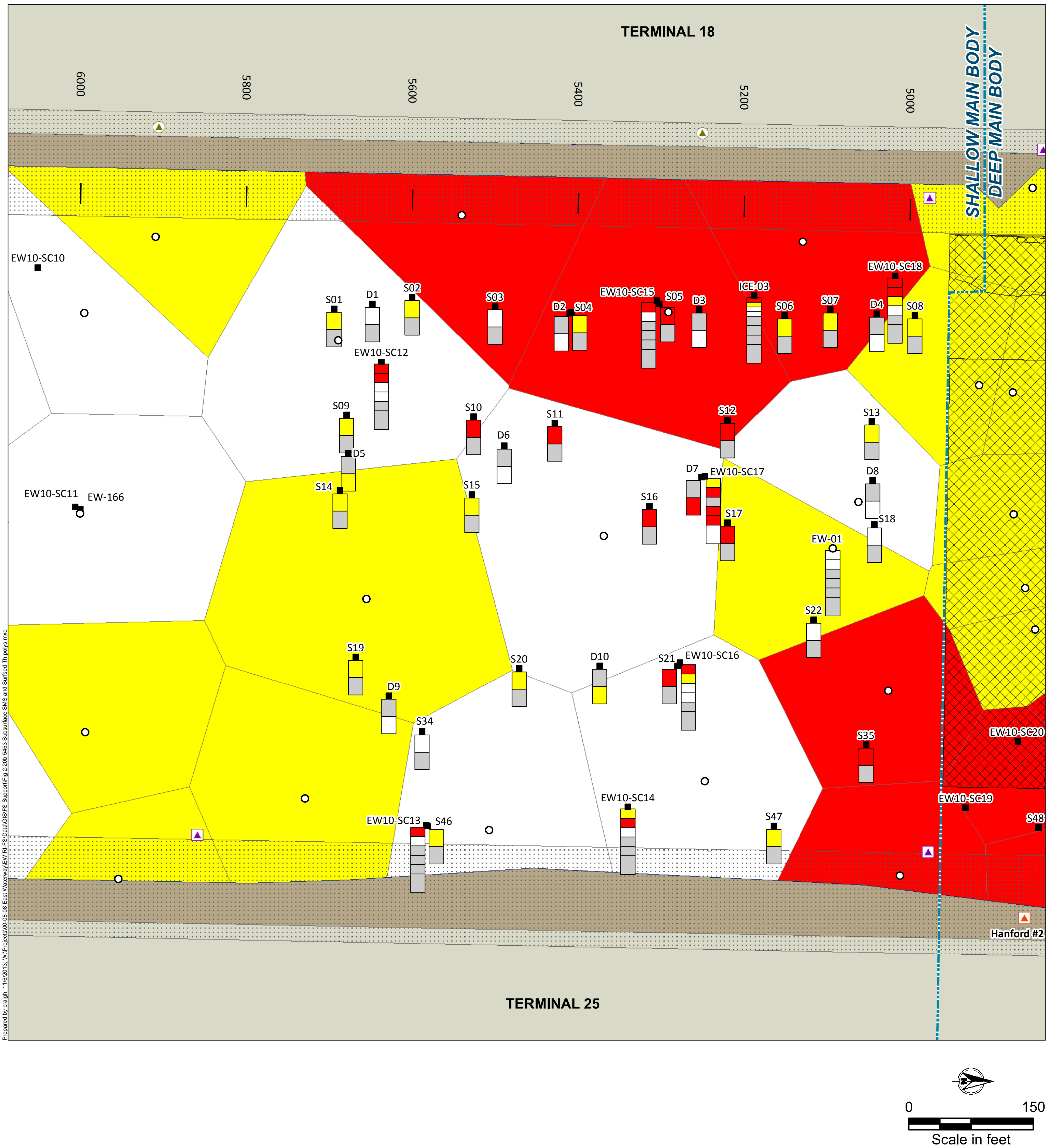


Figure 2-19b
Surface and Subsurface Sediment TBT Concentrations
Feasibility Study
East Waterway Study Area



[a] Thiessen polygons represent final SMS status (chemical criteria and toxicity combined) in surface sediment.

Figure 2-20a
Exceedances of SQS and CSL (Chemical Criteria and Toxicity Combined) Using Thiessen Polygons for the Surface Sediment Dataset
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

■ Subsurface Core Location

SMS Exceedance in Subsurface and Surface Sediment [a]

- > CSL, Detect
- > SQS and ≤ CSL, Detect
- ≤ SQS or Non-detect
- Not Analyzed for This Interval

0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

0 - 4 ft, > 4 ft

[a] Thiessen polygons represent final SMS status (chemical criteria and toxicity combined) in surface sediment.

- ○ Surface Sediment Sampling Location
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- CSO
- CSO/Storm Drain
- Storm Drain
- Unknown
- East Waterway Study Area Boundary

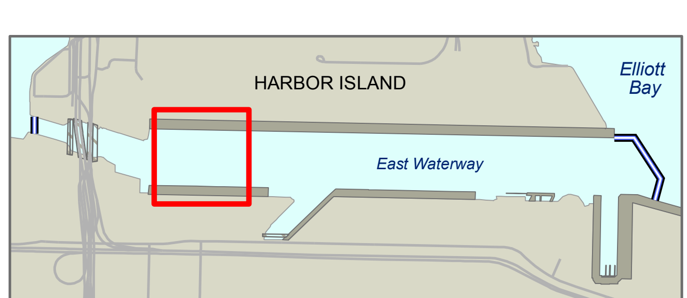
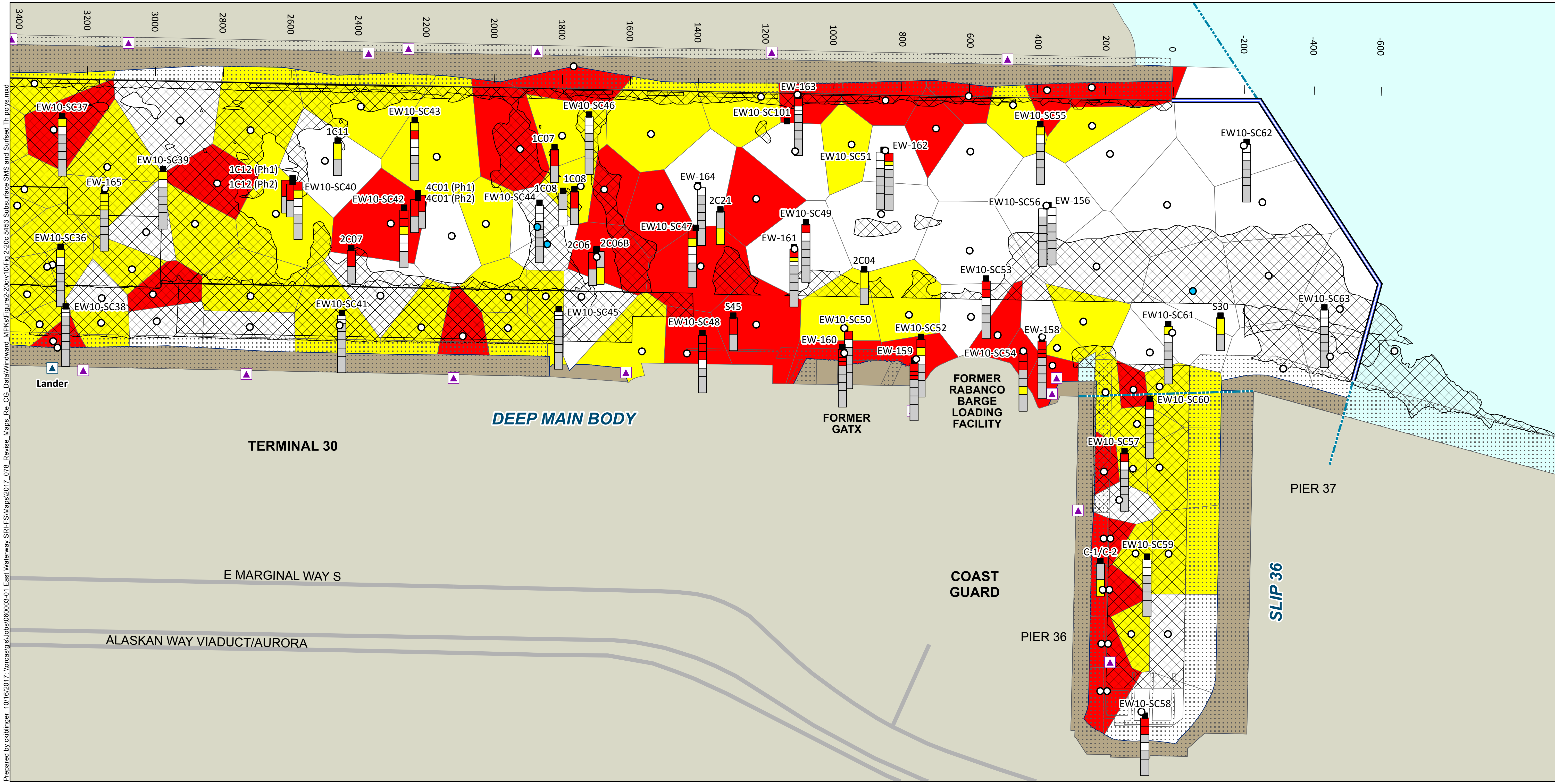


Figure 2-20b
Exceedances of SQS and CSL (Chemical Criteria and Toxicity Combined) Using Thiessen Polygons for the Surface Sediment Dataset
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

- ■ Subsurface Core Location

SMS Exceedance in Subsurface and Surface Sediment [a]

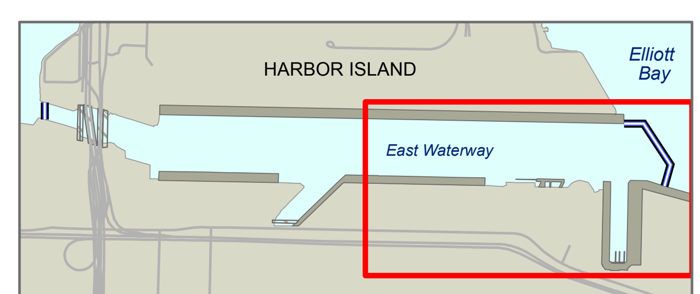
- > CSL, Detect
- > SQS and ≤ CSL, Detect
- ≤ SQS or Non-detect
- Not Analyzed for This Interval
- ○ Surface Sediment Sampling Location
- ● Restricted Analyte Location[b]

0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

0 - 4 ft, > 4 ft

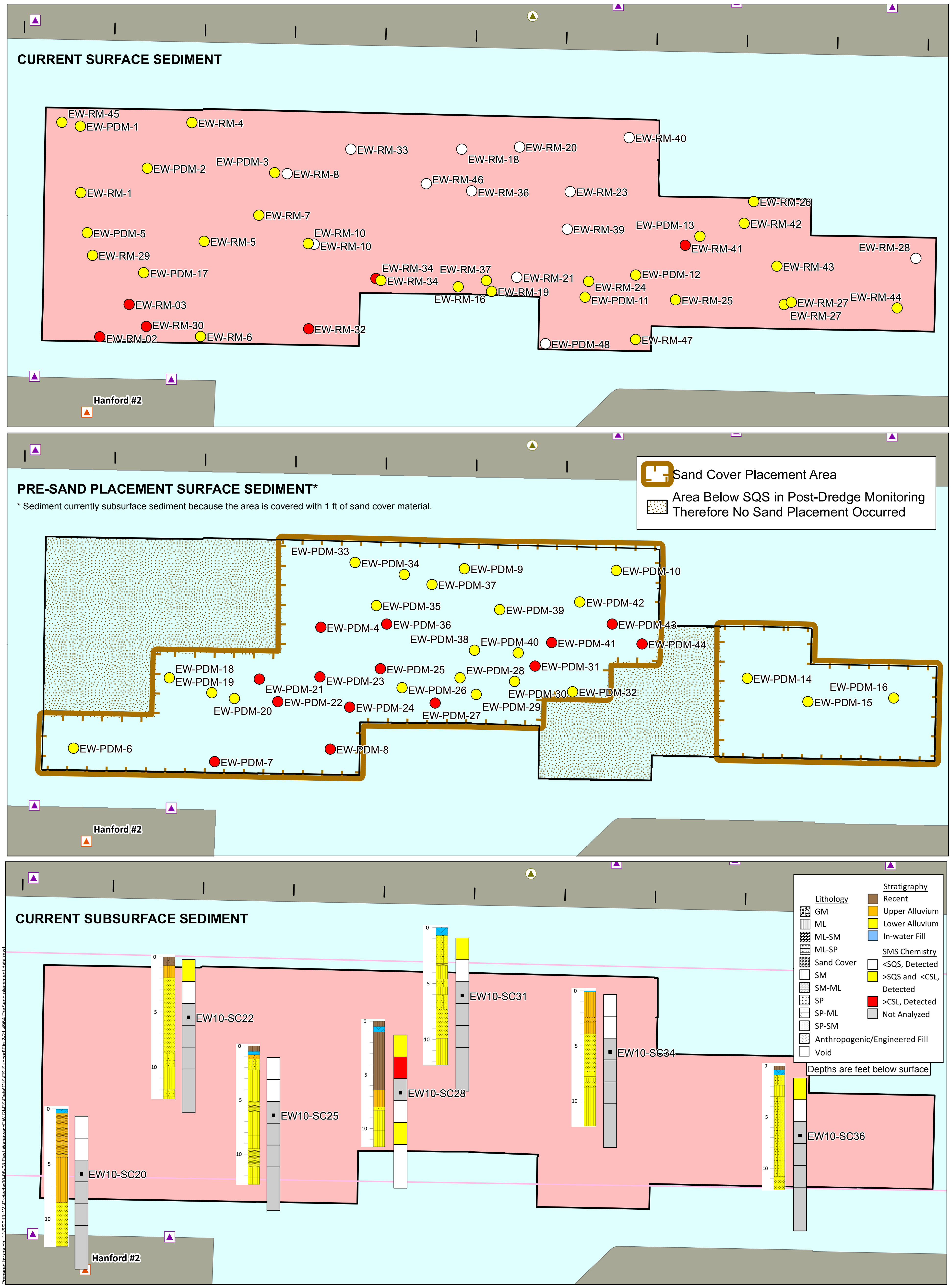
- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary



0 600
Scale in feet

[a] Thiessen polygons represent final SMS status (chemical criteria and toxicity combined) in surface sediment.
[b] Not analyzed for SVOCs, phthalates, or metals other than mercury.

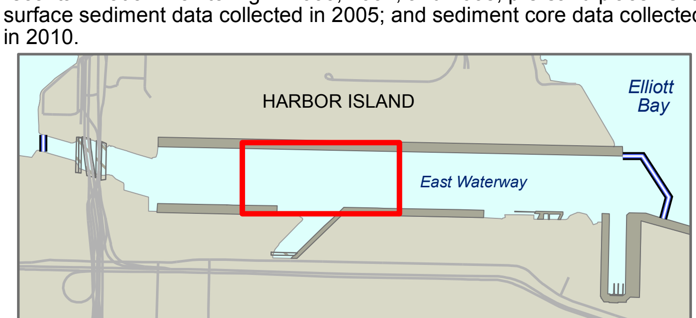
Figure 2-20c
Exceedances of SQS and CSL (Chemical Criteria and Toxicity Combined) Using Thiessen Polygons for the Surface Sediment Dataset
Feasibility Study
East Waterway Study Area



Surface Sediment SMS Status

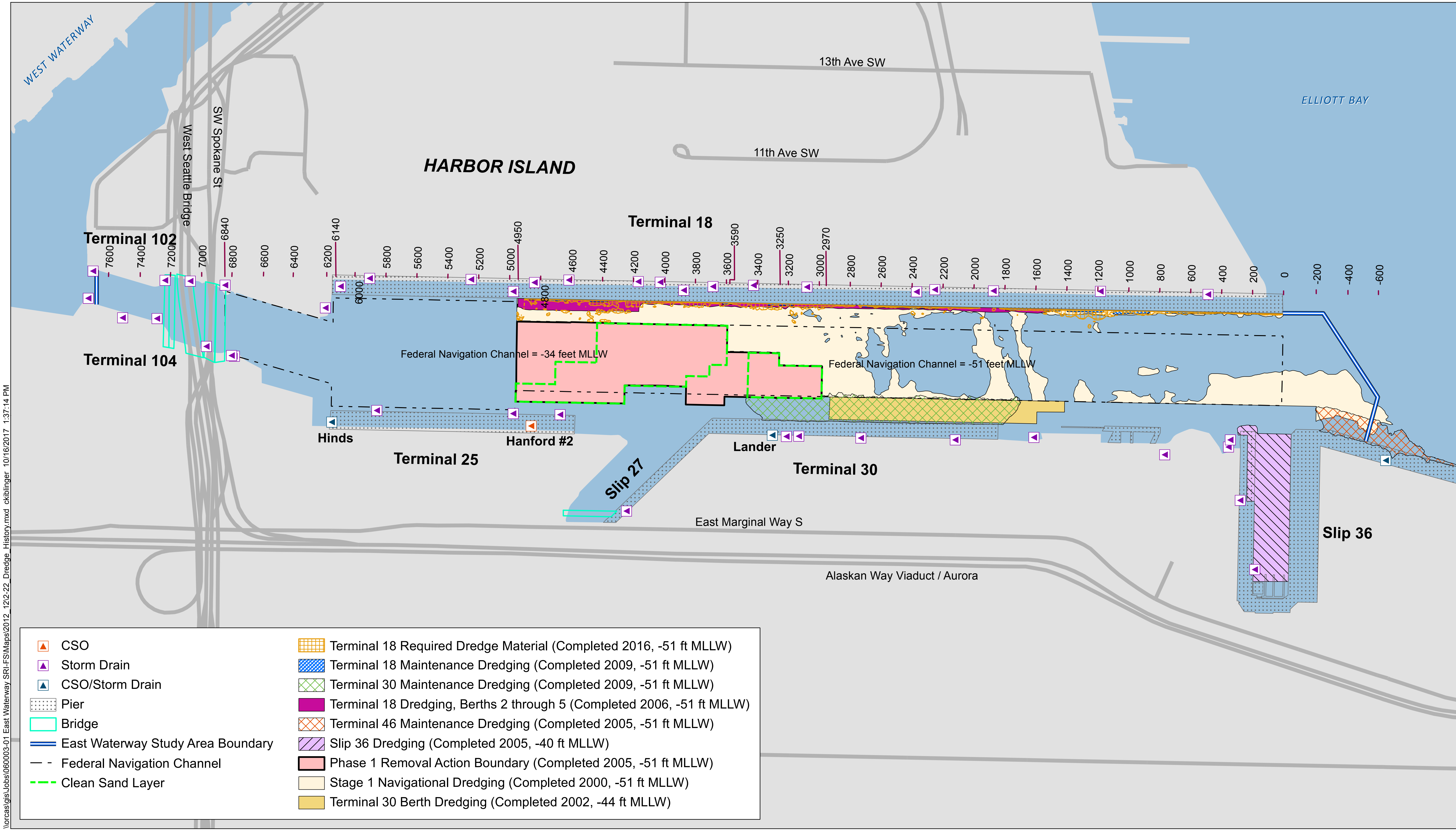
- > CSL, Detect
- > SQS and ≤ CSL, Detect
- ≤ SQS or Non-detect
- CSO
- Storm Drain
- Unknown Outfall
- Dock/Pier
- Phase 1 Removal Action Boundary

Note: Phase 1 data set consists of: post sand placement data collected for recontamination monitoring in 2006, 2007, and 2008; pre-sand placement surface sediment data collected in 2005; and sediment core data collected in 2010.



0 150
Scale in feet

Figure 2-21
Surface and Subsurface Sediment Datasets Associated with the Phase 1 Dredge Area
Feasibility Study
East Waterway Study Area



\\orcas\gis\Jobs\060003-01 East Waterway SRI-FS\Maps\2012_12\2-22_Dredge_History.mxd ckiblinger 10/16/2017 1:37:14 PM

NOTES:
1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. Dredge activities listed indicate events since 2000.

Figure 2-22
Recent Dredge History
Feasibility Study
East Waterway Study Area

3 RISK ASSESSMENT SUMMARY

The baseline ERA (Windward 2012a) and baseline HHRA (Windward 2012b) were completed for the EW in 2012. This section summarizes the findings of both risk assessments, which are used in Section 4 of this FS to aid in establishing RAOs and PRGs.

The ERA (Windward 2012a) is discussed in Section 3.1, and presents the estimated risks for the benthic invertebrate community and for crabs, fish, and wildlife species. These receptors are exposed to contaminants in the EW primarily through contact with sediment and water, or through consumption of prey species found in the EW.

The HHRA (Windward 2012b) is discussed in Section 3.2, and presents the estimated risks for people who may be exposed to contaminants in the EW through consumption of resident seafood from the EW or through direct contact with sediment or water.

The RBTCs, discussed in Section 3.3, represent calculated sediment and tissue concentrations estimated to be protective of a particular receptor for a given exposure pathway and target risk level. RBTCs were derived in the SRI (Windward and Anchor QEA 2014) based on the baseline ERA (Windward 2012a) and HHRA (Windward 2012b). The RBTCs are also presented in this FS because they are used, along with other information, to establish PRGs in Section 4. Finally, this section concludes with a summary of the key findings from the risk assessments (Section 3.4).

3.1 Baseline Ecological Risk Assessment

The baseline ERA (Windward 2012a) estimated risks for ecological receptors in the EW that may be exposed to contaminants in sediment, surface water, porewater, and prey items.

Nine receptors of concern[19] were selected in the baseline ERA to be representative of groups of organisms in the EW with the same exposure pathways and that will be protective or

[19] Key considerations for selecting receptors of concern were the potential for direct or indirect exposure to sediment-associated contaminants, human and ecological significance, site use, sensitivity to COPCs at the site, susceptibility to biomagnification of COPCs, and data availability.

representative of other species that were not explicitly evaluated. These receptors of concern include the benthic invertebrate community; crabs; English sole, brown rockfish, and juvenile Chinook salmon (collectively discussed as "fish"); and pigeon guillemot, osprey, river otter, and harbor seal (collectively discussed as "wildlife species").

A conservative risk-based screening process first identified contaminants of potential concern (COPCs) for the ERA, which included a comparison of maximum contaminant concentrations with established criteria or literature-based toxicity reference values (TRVs; Windward 2012a). In this process, contaminant concentrations in sediment, surface water, porewater, and aquatic biota were compared to risk-based screening levels. Those contaminants present at concentrations above the screening levels or demonstrating the potential for unacceptable effects were identified as COPCs and underwent further risk analysis in the ERA as follows:

- Risks for the benthic community were estimated by comparing COPC concentrations in sediment with the numerical criteria of the Washington State SMS. Risks were also estimated based on site-specific sediment toxicity tests; a comparison of VOC concentrations in porewater to aquatic toxicity data; a comparison of PCB, mercury, and TBT concentrations in benthic invertebrate tissues to concentrations associated with adverse effects; and a comparison of COPC concentrations in surface water to marine WQC.
- Risks for fish and crabs were estimated by comparing COPC concentrations in fish and crab tissue with tissue residues associated with effects on survival, growth, or reproduction. In addition, risks for fish and crabs were estimated by comparing COPC concentrations in surface water to marine WQC.
- Risks for fish were also evaluated by comparing COPC concentrations[20] in fish diets (based on prey and sediment concentrations, or stomach content concentrations) to dietary concentrations that have been shown to cause adverse effects on survival, growth, or reproduction.
- For wildlife, risks were estimated based on calculations of daily doses of COPCs derived from the ingestion of sediment, water, and prey species. Risks were then

[20] This method was applied to metal and PAH COPCs.

estimated by comparing those doses with doses that have been shown to cause adverse effects on survival, growth, or reproduction.

Risks based on surface water, porewater, tissue, and dietary exposure were estimated by comparing COPC concentrations in the media of concern to WQC or TRVs, including no-observed-adverse-effect levels (NOAELs) and lowest-observed-adverse-effect levels (LOAELs). Risks were estimated by calculating hazard quotients (HQs) as the ratio of the COPC concentrations in the media of concern to the toxicity value as represented by SMS, WQC, or selected NOAELs and LOAELs. The risks estimated for each of these receptors are summarized in the following sections.

3.1.1 Benthic Invertebrate Community

Contaminant concentrations in surface sediments were compared to the SQS[21] and the CSL (WAC 173-204-320 and WAC 173-204-562, respectively) numerical chemical values of the SMS. Concentrations of total dichlorodiphenyl-trichloroethanes (DDTs) in surface sediment were compared with DMMP sediment quality guidelines because SMS values are not available for total DDTs. A contaminant was selected as a COC if its concentration was found to be above the SQS criteria (or above the DMMP guidelines in the case of total DDTs) in one or more sediment samples from the EW. Thirty contaminants were identified as COCs for the benthic invertebrate community based on surface sediment data (Table 3-1).

When contaminant concentrations in surface sediment exceed the SMS criteria, the potential exists for minor adverse effects on the benthic invertebrate community living in intertidal and subtidal sediment. The SQS were exceeded in approximately 61% (96 acres) of the EW study area. Of these 96 acres, a higher likelihood for minor adverse effects was identified in 36 acres, corresponding to approximately 23% of the EW, where contaminant concentrations or biological effects resulted in exceedances of the CSL of the SMS. The other 59 acres (38% of the EW) had contaminant concentrations or biological effects that exceeded the SQS but

[21] The revised SMS have changed the term SQS to sediment cleanup objective (SCO) in Section 204-562 of the WAC, but still uses the term SQS in Section 204-320 of the WAC. Therefore, the term SQS has been retained for this FS and is synonymous with "SCO based on protection of the benthic community" in the revised SMS.

Table 3-1

Summary of COCs and Selection of Risk Driver COCs for Benthic Invertebrates Based on Surface Sediment Exposure

COC	SMS Criteria			No. of Detected Concentrations in Surface Sediments		Risk Driver?
	Unit	SQS	CSL	> SQS, ≤ CSL	> CSL	
Metals						
Arsenic	mg/kg dw	57	93	0	3	Yes
Cadmium		5.1	6.7	1	1	Yes
Mercury		0.41	0.59	41	10	Yes
Zinc		410	960	4	2	Yes
PAHs						
2-Methylnaphthalene	mg/kg OC	38	64	0	3	Yes
Acenaphthene		16	57	11	13	Yes
Anthracene		220	1,200	5	2	Yes
Benzo(a)anthracene		110	270	7	7	Yes
Benzo(a)pyrene		99	210	7	8	Yes
Benzo(g,h,i)perylene		31	78	7	8	Yes
Total benzofluoranthenes		230	450	9	3	Yes
Chrysene		110	460	9	6	Yes
Dibenzo(a,h) anthracene		12	33	15	7	Yes
Dibenzofuran		15	58	10	9	Yes
Fluoranthene		160	1,200	14	9	Yes
Fluorene		23	79	2	5	Yes
Indeno(1,2,3-cd) pyrene		34	88	10	7	Yes
Phenanthrene		100	480	6	9	Yes
Pyrene		1,000	1,400	0	3	Yes
Total HPAH		960	5,300	11	13	Yes
Total LPAH		370	780	5	2	Yes
Phthalates						
Bis(2-ethylhexyl) phthalate	mg/kg OC	47	78	4	5	Yes
Butyl benzyl phthalate		4.9	64	16	0	Yes
Di-n-butyl phthalate		220	1,700	0	1	Yes
Other SVOCs						
1,4-Dichlorobenzene	mg/kg OC	3.1	9	21	9	Yes
2,4-Dimethylphenol	µg/kg dw	29	29	0	9	Yes

Table 3-1
Summary of COCs and Selection of Risk Driver COCs for Benthic Invertebrates Based on Surface Sediment Exposure

COC	SMS Criteria			No. of Detected Concentrations in Surface Sediments		Risk Driver?
	Unit	SQS	CSL	> SQS, ≤ CSL	> CSL	
n-Nitrosodiphenylamine	mg/kg OC	11	11	0	3	Yes
Phenol	µg/kg dw	420	1,200	5	0	Yes
PCBs						
Total PCBs	mg/kg OC	12	65	137	23	Yes
Pesticides						
Total DDTs	µg/kg dw	6.9[a]	69[a]	2	0	No

Notes:
This table is derived from Table A.6-1 of the ERA (Windward 2012a), updated with 8 surface sediment samples from Slip 36 (see Section 2.10).
a. No SQS or CSL values are available for total DDTs. Thus, the comparison is with the DMMP SL and ML.

µg/kg – micrograms per kilogram
COC – contaminant of concern
CSL – cleanup screening level
DDT – dichlorodiphenyltrichloroethane
DMMP – Dredged Material Management Program
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
ML – maximum level
OC – organic carbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RI – remedial investigation
SL – screening level
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SVOC – semivolatile organic compound

not the CSL representing a potential for minor adverse effects in these areas. The remaining 39% of the EW (61 acres) is considered unlikely to have adverse effects on the benthic invertebrate community.[22]

VOCs in sediment porewater were considered unlikely to pose a risk to the benthic invertebrate community, except for naphthalene, which had a concentration that exceeded toxicity data representing the lowest observed effect concentration (LOEC) at one location. Naphthalene was selected as a COC for the benthic invertebrate community based on porewater exposure.

[22] As noted in Section 2.10.1, these values differ slightly from those presented in the EW SRI (Windward and Anchor QEA 2014) due to inclusion of Slip 36 data collected in 2014. Areas are based on 157 acres of sediment in the study area.

The potential for adverse effects from exposure to TBT was identified for benthic invertebrates in 2 of the 12 benthic invertebrate tissue sampling areas because the LOAEL TRV for TBT was exceeded in samples collected from those areas. Mercury and PCBs were considered unlikely to pose a risk to the benthic invertebrate community based on concentrations in tissue. TBT was selected as a COC based on concentrations in benthic invertebrate tissue.

Finally, there is uncertainty in the risk posed to the benthic invertebrate community from exposure to TBT in surface water because the TBT concentration exceeded the recommended federal chronic WQC in one sample, but was undetected in the remaining 30 samples with reporting limits (RLs) slightly exceeding the WQC.[23] Therefore, TBT was also selected as a COC for benthic invertebrates based on the surface water evaluation.

3.1.2 Crabs, Fish, and Wildlife Species

COCs were identified for crabs, fish, and wildlife species if LOAEL-based HQs were greater than or equal to 1. In addition, COCs were defined for crabs and fish if exposure concentrations in surface water exceeded chronic WQC or TRV.

Cadmium, copper, and zinc were identified as COCs for crabs based on the tissue residues evaluation, indicating the potential for adverse effects. The tissue residue evaluation for fish resulted in the identification of TBT as a COC for brown rockfish and total PCBs as COCs for English sole and brown rockfish.

Cadmium was identified as a COC for juvenile Chinook salmon, English sole, and brown rockfish based on the dietary exposure evaluation. In addition, the potential for adverse effects was identified for English sole from exposure to copper and vanadium in the diet.

[23] It should be noted that all of the RL values were above the chronic marine ambient WQC value of 0.0074 micrograms per liter (µg/L). The surface water samples were analyzed by the most sensitive, commercially available analytical method. The TBT method detection limit (MDL) values were below the chronic marine ambient WQC, and the laboratory was required to report values between the MDL and the RL as estimated. No estimated values were reported.

No COCs were identified for fish or crabs based on the surface water evaluation, or for wildlife based on the dietary exposure evaluation.

3.1.3 Risk Driver COCs for Ecological Receptors

A subset of the COCs was identified as risk drivers for ecological receptors based on the risk estimates, uncertainties discussed in the ERA (Windward 2012a), and Puget Sound Ambient Monitoring Program (PSAMP) rural Puget Sound concentrations in accordance with EPA (1992, 1997a, 1997b, 1998) guidance and consistent with the LDW ERA (Windward 2007a). The rationale for identifying these risk driver COCs can be found in Section 7 of the baseline ERA (Windward 2012a) and is summarized in Tables 3-1 and 3-2. Risk driver COCs for ecological receptors of concern were selected by considering: 1) the uncertainty in risk estimates based on quantity and quality of exposure and effects data, 2) magnitude of exposure concentrations compared to TRVs, and 3) comparison of concentrations in EW sediment with PSAMP rural Puget Sound background concentrations in sediment.

Table 3-2
Summary of COCs and Selection of Risk Drivers for Ecological Receptors[a]

Receptor of Concern – Type of Evaluation	COC[b]	LOAEL-based HQ	Risk Driver?	Rationale for Selection or Exclusion as Risk Driver
Benthic invertebrate community – tissue	TBT	3.3	Yes	LOAEL-based HQs greater than 1.0 in two areas of the EW; low uncertainty in exposure data
Benthic invertebrate community – surface water	TBT	1.4	No	High uncertainty in surface water dataset; only one detected value; low LOAEL-based HQ
Benthic invertebrate community – porewater	Naphthalene	6	No	High uncertainty in effects data; only one porewater sample had a concentration exceeding the low-effect HQ; naphthalene did not exceed the SMS in any sediment samples
Crab – tissue	Cadmium	1.4	No	Three COCs identified for crab were not selected as risk drivers because
	Copper	1.1	No	

Table 3-2
Summary of COCs and Selection of Risk Drivers for Ecological Receptors[a]

Receptor of Concern – Type of Evaluation	COC[b]	LOAEL-based HQ	Risk Driver?	Rationale for Selection or Exclusion as Risk Driver
	Zinc	1.5	No	site sediment concentrations were similar to PSAMP rural Puget Sound concentrations (cadmium and copper) and because of uncertainties in the effects data for all three COCs, including the lack of toxicity data for crabs
English sole – tissue	Total PCBs	1.6 – 7.9[c]	Yes	HQ based on higher LOAEL TRV, which was associated with significant effects, was >1.0; low uncertainty in exposure data
Brown rockfish – tissue	Total PCBs	2.3 – 12[c]	Yes	
	TBT	1.4	No	High uncertainty in toxicity dataset; exposure concentration representing the population of rockfish did not exceed LOAEL; low LOAEL-based HQ
Juvenile Chinook salmon – diet	Cadmium	1.0	No	Three dietary COCs for fish were not selected as risk drivers because the site sediment concentrations were similar to PSAMP rural Puget Sound concentrations and because of uncertainties in exposure or effects data
English sole – diet	Cadmium	2.4	No	
	Copper	1.1	No	
	Vanadium	1.9	No	
Brown rockfish – diet	Cadmium	2.5	No	

Notes:
a. No COCs were identified for birds and mammals. Benthic risk drivers are presented separately in the text below.
b. A contaminant was identified as a COC if the LOAEL-based HQ was greater than or equal to 1.0; however, for juvenile Chinook salmon, NOAEL-based HQs were used because it is a listed species.
c. HQs were calculated from a range of effects concentrations because of uncertainty in the TRVs.

COC – contaminant of concern
HQ – hazard quotient
LOAEL – lowest-observed-adverse-effect level
NOAEL – no-observed-adverse-effect level
PCB – polychlorinated biphenyl
PSAMP – Puget Sound Ambient Monitoring Program
RI – remedial investigation
TBT – tributyltin

In the baseline ERA (Windward 2012a), 30 contaminants were selected as COCs for benthic invertebrates. Of these, 29 contaminants were selected as risk drivers for benthic invertebrates because they had concentrations greater than the SQS in at least one sediment sample (Table 3-1) and SMS is a key regulation governing sediment remediation in the State of Washington. The remaining COC, total DDTs, was not selected as a risk driver because of the low detection frequency, known analytical uncertainties from PCB interference, and uncertainties in the effects data. TBT was identified as a risk driver for the benthic invertebrate community for the tissue evaluation because of two LOAEL-based HQs greater than 1 and low uncertainty in the exposure data. Total PCBs was selected as a risk driver for English sole and brown rockfish because PCBs in tissue residues exceeded the higher LOAEL TRV that was associated with significant effects and uncertainties are low in the exposure data (Table 3-2). Non-risk driver COCs are evaluated to assess the potential for risk reduction following remedial actions; the results of this analysis are presented in Section 9 of this FS.

3.2 Baseline Human Health Risk Assessment

The baseline HHRA (Windward 2012b) estimated risks to people from exposure to contaminants in EW seafood, sediments, and water. The exposures were assumed to occur through consumption of resident seafood harvested from the EW; direct contact with sediments during netfishing, clamming, or habitat restoration (which include the pathways of dermal contact and incidental ingestion of sediment); and direct contact with surface water while swimming. To the extent possible, this HHRA is consistent with the approach and methods that were approved by EPA for use in the HHRA for the LDW (Windward 2007a).

Using EPA guidance, a risk-based screening was first performed to identify the COPCs to be evaluated. This screening process was based on an exceedance of the screening criteria (i.e., the risk-based concentration) by either the maximum detected concentrations or analytical RLs (for samples with non-detected concentrations). The COPCs for each exposure scenario were then evaluated to estimate risks and determine COCs.

Risks estimated for the seafood consumption and direct exposure scenarios evaluated in the HHRA (Windward 2012b) are discussed in the following subsections. In January 2017, subsequent to the HHRA, the benzo(a)pyrene cancer slope factor (which is used to calculate the excess cancer risk for cPAHs) was updated in EPA's Integrated Risk Information System (IRIS) database. This section includes updated lifetime excess cancer risk estimates for cPAHs based on the updated slope factor as compared with those presented in HHRA, and includes updated the COC and risk-driver designations for cPAHs. An addendum to the HHRA describes the effects of the cancer slope factor change for the assessment of cPAHs in the HHRA (Windward 2019).

3.2.1 Risks Associated with the Seafood Consumption Pathway

No seafood consumption surveys specific to the EW were available for use in the HHRA (Windward 2012b). Therefore, the EW HHRA used seafood consumption rates developed by EPA based on data collected from other areas of Puget Sound for tribal consumers and from an EPA seafood consumption study for Asian and Pacific Islanders (API) in the King County area. The seafood consumption rates used in the EW HHRA are the same as those used to evaluate risks in the LDW HHRA (Windward 2007a, 2009).

Seafood consumption scenarios with different levels of exposure were evaluated in the baseline HHRA to provide a broad range of risk estimates. Reasonable maximum exposure (RME) estimates, which will be used for making decisions about the need for remediation at the site, included the following seafood consumption rates:

- Tulalip tribal consumption rates for adults and children from EPA's tribal framework document (EPA 2007)
- Seafood consumption rates for API adults, modified by EPA based on the results of a survey of API consumers (EPA 1999b) to reflect rates by individuals that harvest seafood only within King County

RME scenarios are the highest exposure that is reasonably expected to occur at a site. The RME, by definition, likely overestimates exposure for many individuals. Additionally, it should be noted that the tribal consumption rates are likely overestimates of current consumption of resident seafood specifically from the EW. However, such rates may be achieved in the EW at some future time.

Other seafood consumption scenarios were also evaluated in the baseline HHRA (Windward 2012b). These other scenarios included consumption rates estimated using: 1) Suquamish tribal consumption rates from EPA's tribal framework document (EPA 2007); 2) "average exposure" scenarios using central tendency (CT) consumption rate estimates; and 3) a "unit risk" scenario based on an assumed one seafood meal per month. Estimates for the unit risk scenario are useful for risk communication because individuals can determine what their risk might be for various seafood consumption practices. For the EW, given the limited quantity of current or potential shellfish habitat (particularly high-quality habitat), the Tulalip Tribes' rate was selected, as approved by EPA (Windward 2010e), to characterize the RME seafood consumption risks in the EW. Inasmuch as the EW is within the U&A fishing area of the Suquamish Tribe, and the Suquamish Tribe requested that their seafood consumption data be used to characterize risk, the EW HHRA also evaluated risk using Suquamish Tribe consumption rates. Although, EPA's tribal framework supports consistency in internal EPA policy regarding tribal seafood consumption risk assessment, the recommendations of the framework (EPA 2007) do not replace or supersede the need for consultation between EPA and the tribes to develop site-specific risk assessments. Discussions between EPA and the Suquamish Tribe did not result in tribal concurrence regarding the use of the Tulalip tribal consumption rates as the RME scenario for the EW HHRA. The Suquamish Tribe requested that the tribal RME scenario be represented as a range of exposures based on the Tulalip and Suquamish consumption rates. Rather, the use of the Tulalip rates represents an EPA policy decision. However, the Muckleshoot and Suquamish Tribes recognize that sediment cleanup levels for bioaccumulative risk driver contaminants based on seafood consumption risks will likely be below background, regardless of whether Tulalip or Suquamish consumption rates are used to develop cleanup levels. For this reason, the tribes have not pursued their disagreement with EPA more vigorously regarding the selection of the Tulalip Tribes' rate to characterize RME seafood consumption risks for the EW. The tribes regard the EW seafood consumption rate decision to be site-specific and do not regard it as being precedent-setting.

It is noted that there is considerable uncertainty about the applicability of seafood consumption rates in the baseline HHRA (Windward 2012b), particularly for clams, given the limited quality of existing or potential future shellfish habitat (particularly high-quality habitat) in the EW. Nonetheless, their use in the HHRA reflects health-protective estimates of risk.

Contaminant concentrations in the tissues of a variety of different resident seafood species (English sole, perch, rockfish, crabs, clams, geoduck, and mussels) were used to represent a typical consumer's diet (i.e., a market basket approach was used to evaluate risks associated with seafood consumption). COCs were then determined by estimating cancer and non-cancer effects for the RME scenarios. Contaminants with an estimated excess cancer risk greater than 1 in 1,000,000 (1×10^{-6}) or a non-cancer HQ greater than 1 were selected as

COCs for the seafood consumption exposure pathway. Eleven COPCs were identified as COCs for the seafood consumption exposure pathway (Table 3-3).[24]

Table 3-3

Summary of COCs for the HHRA

COCs Identified for One or More RME Scenarios	Seafood Consumption Scenarios			Direct Sediment Exposure Scenarios	
	Adult Tribal RME (Tulalip Data)	Child Tribal RME (Tulalip Data)	Adult API RME	Netfishing RME	Tribal Clamming RME
Arsenic	X	X	X	X	X
Cadmium		X			
cPAH (TEQ)	X	X	X	O[a]	X
Pentachlorophenol	X				
Total PCBs	X	X	X		X
PCB (TEQ)	X	X	X		
alpha-BHC	X				
Dieldrin	X		X		
Total chlordane	X				
Heptachlor epoxide	X				
Mirex	X				
Dioxins/furans (TEQ)	X	X	X		
Total TEQ[b]					X

Notes:

a. cPAH TEQ was identified as a COC for netfishing in the HHRA. Subsequent to the HHRA, the cancer slope factor was updated in EPA's Integrated Risk Information System (IRIS) database for benzo[*a*]pyrene. This reduced the cPAH TEQ risks calculated in this FS as compared with the risks calculated in the HHRA. The updated cPAH TEQ netfishing risks for the RME scenario are below 1×10^{-6}, which results in the elimination of cPAH TEQ from the list of COCs for the netfishing RME scenario.The updated risks for cPAH TEQ for all scenarios are documented in the HHRA addendum (Windward 2019) and this section of the FS. Further, because cPAH TEQ is not a COC for netfishing based on updated cancer slope factor, it is also no longer a risk driver for netfishing and therefore is not discussed for this scenario in later sections of the FS (e.g., see Table 3-14).

[24] As presented in Table 3-3, both total PCBs (i.e., the sum of detected Aroclors) and dioxin-like PCB toxic equivalents (TEQs) were identified in the HHRA as COCs. Because these two COCs represent different methods of evaluating the same contaminant, they are counted as one COC in the count presented here. The risk from total PCBs calculated as a sum of detected Aroclors was approximately equal to or up to two times higher than the risk calculated from the PCB TEQ (EW SRI Section 6.3.2; Windward and Anchor QEA 2014). This is because dioxin-like PCBs included in the PCB TEQs are also accounted for as part of the total PCB sum, and thus contribute to cancer risk estimates calculated for total PCBs. Therefore, only total PCBs were retained in the FS for the alternatives analysis.

b. Total TEQ is equal to the sum of PCB TEQ and dioxin/furan TEQ. When excess cancer risks for either PCB TEQ or dioxin/furan TEQ were not independently greater than 1×10^{-6}, the sum of these two chemicals (total TEQ) was identified as a COC if it was greater than this threshold.

API – Asian and Pacific Islander
BHC – benzene hexachloride
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
HHRA – human health risk assessment
O – Retained as a COC in the HHRA, but dropped as a COC in the FS (see table note a)
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
TEQ – toxic equivalent
X – Retained as COC

The total excess cancer risk for all carcinogenic contaminants for the various RME seafood consumption scenarios ranged from 5 in 10,000 (5×10^{-4}) to 1 in 1,000 (1×10^{-3}),[25] with the primary contributors to risk being total PCBs, arsenic, cPAHs, and dioxins/furans (Table 3-4a).[26] In addition, evaluation of non-cancer HQs indicates the potential for adverse effects other than cancer associated with seafood consumption, particularly from total PCBs (Table 3-4b).

To provide additional information regarding the total excess cancer risks for the RME seafood consumption scenarios, Table 3-5 presents a summary of the excess cancer risks for COCs and includes the percentages of the total risks attributable to different COCs and seafood consumption categories (i.e., fish, crabs, clams, geoduck, and mussels). The main contributors to the total excess cancer risk for the RME seafood consumption scenarios were total PCBs (73% to 76% of the total risk), arsenic (13% to 14% of the total risk), cPAHs (1% to 5% of the total risk), and dioxins/furans (7% of the total risk). In addition, Table 3-5 shows that the majority of the arsenic and cPAH risks (73% to 90%) are attributable to clams, while the total PCB and dioxin/furan risk is attributable to several different seafood consumption categories and is more variable across scenarios. For total PCBs, the risk is primarily attributable to benthic fish fillet (16% to 41%), rockfish (9% to 59%), perch (3% to 26%), crab edible meat (3% to 10%), and whole body crab (7% to 9%). For dioxins/furans, the risk is primarily attributable to clams (25% to 31%), crab edible meat (8% to 22%), whole body crab (18%), and rockfish (5% to 35%).

[25] As noted in the footnote above, the total risk estimate includes risks from total PCBs but excludes risks from PCBs from a TEQ perspective to avoid double counting dioxin-like PCB risks posed by coplanar PCB congeners that are already accounted for in the slope factor for PCBs.

[26] Risk associated with many chlorinated pesticides was based largely on non-detect results.

3.2.2 Risks Associated with Direct Sediment Contact

The direct sediment exposure scenarios evaluated in the EW HHRA (Windward 2012b) included two netfishing scenarios (RME and CT), a habitat restoration worker scenario, and three clamming scenarios: 1) tribal RME (120 days per year); 2) high-end exposure included at the request of the Suquamish Tribe (183 days per year); and 3) 7 days per year.[27] As in the LDW HHRA (Windward 2007a), exposure frequency and duration assumptions for the evaluation of direct sediment exposure under the commercial netfishing scenario were based on site use information collected from the Muckleshoot Indian Tribe, which conducts commercial netfishing for adult salmon in the Green/Duwamish River, including the EW. No site-specific information was available to estimate exposure for the clamming and habitat restoration scenarios and, thus, exposure parameters were (when possible) consistent with

the LDW and/or were based on default EPA values and best professional judgment. Netfishing can occur throughout the EW (i.e., in intertidal and subtidal areas), while clamming and habitat restoration activities would occur in specific areas of the EW (i.e., in specific intertidal areas), which are shown in Figure 3-1. Intertidal sediment areas (i.e., not riprap) were identified as potential clamming areas and were surveyed for the EW SRI as described in Sections 2.9.3 and 2.9.4 herein.

Excess cancer risks for the direct sediment exposure scenarios were much lower than those for the seafood consumption scenarios (Table 3-6). Excess cancer risks for all scenarios were less than the upper end of EPA's risk range (1 in 10,000 [1×10^{-4}]), with total excess cancer risks equal to 5 in 1,000,000 (5×10^{-6}) for the netfishing RME scenario and 2 in 100,000 (2×10^{-5}) for the tribal clamming RME scenario. Cancer risks were highest for arsenic, which accounts for 63% to 67% of the total excess cancer risk for the RME scenarios. cPAHs, PCBs, and dioxin/furan TEQ were lesser contributors. No COPCs had non-cancer HQs greater than 1 for any of the direct sediment exposure scenarios. In addition, the total hazard index (HI) for each exposure scenario did not exceed 1. Therefore, non-cancer hazard was not the basis for selection of any direct contact COC.

[27] The EW HHRA does not include an evaluation of the child beach play scenario because of the lack of suitable exposure areas.

Table 3-4a
Estimated Excess Cancer Risks for the HHRA Seafood Consumption Scenarios

COPC[a]	Estimated Excess Cancer Risk											
	Adult Tribal RME (Tulalip Data)	Adult Tribal CT (Tulalip Data)	Child Tribal RME (Tulalip Data)	Child Tribal CT (Tulalip Data)	Adult Tribal (Suquamish Data)	Adult API RME	Adult API CT	Adult One Meal per Month				
								Benthic Fish	Clam	Crab	Pelagic Fish, Rockfish	Pelagic Fish, Perch
Arsenic[b]	2×10^{-4}	1×10^{-5}	4×10^{-5}	4×10^{-6}	2×10^{-3}	8×10^{-5}	2×10^{-6}	3×10^{-7}[c]	1×10^{-5}	2×10^{-6}	7×10^{-7}	2×10^{-6}
cPAHs (TEQ)[d]	1×10^{-5}	6×10^{-7}	1×10^{-5}	1×10^{-6}	1×10^{-4}	7×10^{-6}	1×10^{-7}	2×10^{-8}	1×10^{-6}	5×10^{-8}	1×10^{-8}	7×10^{-8}
1,4-Dichlorobenzene	1×10^{-6}[e]	7×10^{-8}[e]	2×10^{-7}[e]	3×10^{-8}[e]	7×10^{-6}[e]	4×10^{-7}[e]	8×10^{-9}[e]	4×10^{-8}[c]	4×10^{-8}[c]	4×10^{-8}[c]	4×10^{-8}[c]	2×10^{-7}[c]
Pentachlorophenol	2×10^{-6}[e]	4×10^{-8}[e]	4×10^{-7}[e]	2×10^{-8}[e]	2×10^{-5}[e]	3×10^{-7}	4×10^{-9}	1×10^{-8}[c]	4×10^{-8}	1×10^{-8}[c]	1×10^{-8}[c]	3×10^{-8}[c]
Total PCBs	1×10^{-3}	5×10^{-5}	2×10^{-4}	2×10^{-5}	9×10^{-3}	4×10^{-4}	7×10^{-6}	2×10^{-4}	6×10^{-6}	1×10^{-5}	4×10^{-4}	1×10^{-4}
PCBs (TEQ)[f]	7×10^{-4}	4×10^{-5}	1×10^{-4}	2×10^{-5}	6×10^{-3}	3×10^{-4}	8×10^{-6}	1×10^{-4}	5×10^{-6}	1×10^{-5}	3×10^{-4}	9×10^{-5}
Total DDTs	1×10^{-6}	9×10^{-8}	2×10^{-7}	4×10^{-8}	1×10^{-5}	6×10^{-7}	1×10^{-8}	2×10^{-7}	2×10^{-8}	2×10^{-8}[c]	5×10^{-7}	2×10^{-7}
alpha-BHC	4×10^{-6}[e]	2×10^{-7}[e]	7×10^{-7}[e]	1×10^{-7}[e]	2×10^{-5}[e]	9×10^{-7}[e]	3×10^{-8}[e]	1×10^{-7}[c]	1×10^{-7}[c]	1×10^{-7}[c]	2×10^{-7}	1×10^{-7}[c]
beta-BHC	1×10^{-6}[e]	7×10^{-8}[e]	2×10^{-7}[e]	3×10^{-8}[e]	7×10^{-6}[e]	3×10^{-7}[e]	8×10^{-9}[e]	4×10^{-8}[c]	4×10^{-8}[c]	3×10^{-8}[c]	4×10^{-8}[c]	3×10^{-8}[c]
Dieldrin	8×10^{-6}[e]	5×10^{-7}[e]	1×10^{-6}[e]	2×10^{-7}[e]	5×10^{-5}[e]	2×10^{-6}[e]	7×10^{-8}[e]	2×10^{-7}	3×10^{-7}[c]	3×10^{-7}[c]	4×10^{-7}	5×10^{-7}
Total chlordane	2×10^{-6}	9×10^{-8}	3×10^{-7}	4×10^{-8}	1×10^{-5}	7×10^{-7}	1×10^{-8}	4×10^{-8}	8×10^{-8}	2×10^{-8}[c]	1×10^{-7}	5×10^{-8}
Heptachlor	1×10^{-6}[e]	7×10^{-8}[e]	2×10^{-7}[e]	3×10^{-8}[e]	7×10^{-6}[e]	3×10^{-7}[e]	1×10^{-8}[e]	4×10^{-8}[c]	4×10^{-8}[c]	4×10^{-8}[c]	5×10^{-8}[c]	4×10^{-8}[c]
Heptachlor epoxide	2×10^{-6}[e]	2×10^{-7}[e]	4×10^{-7}[e]	7×10^{-8}[e]	1×10^{-5}[e]	7×10^{-7}[e]	2×10^{-8}[e]	9×10^{-8}[c]	9×10^{-8}[c]	9×10^{-8}[c]	1×10^{-7}	9×10^{-8}[c]
Mirex	4×10^{-6}[e]	3×10^{-7}[e]	8×10^{-7}[e]	1×10^{-7}[e]	3×10^{-5}[e]	1×10^{-6}[e]	4×10^{-8}[e]	2×10^{-7}[c]	2×10^{-7}[c]	2×10^{-7}[c]	4×10^{-7}	2×10^{-7}[c]
Dioxin/furan (TEQ)[f]	1×10^{-4}	6×10^{-6}	2×10^{-5}	3×10^{-6}	7×10^{-4}	4×10^{-5}	1×10^{-6}	5×10^{-6}	3×10^{-6}	3×10^{-6}	2×10^{-5}	9×10^{-6}
Total TEQ (dioxins/furans and coplanar PCBs)	8×10^{-4}	5×10^{-5}	1×10^{-4}	2×10^{-5}	7×10^{-3}	3×10^{-4}	9×10^{-6}	1×10^{-4}	8×10^{-6}	1×10^{-5}	3×10^{-4}	1×10^{-4}
Total excess cancer risk (excluding PCB TEQ)[g]	**1×10^{-3}**	**7×10^{-5}**	**3×10^{-4}**	**3×10^{-5}**	**1×10^{-2}**	**5×10^{-4}**	**1×10^{-5}**	**2×10^{-4}**	**2×10^{-5}**	**2×10^{-5}**	**4×10^{-4}**	**1×10^{-4}**
Total excess cancer risk (excluding total PCBs)[h]	**1×10^{-3}**	**6×10^{-5}**	**2×10^{-4}**	**3×10^{-5}**	**9×10^{-3}**	**4×10^{-4}**	**1×10^{-5}**	**1×10^{-4}**	**2×10^{-5}**	**2×10^{-5}**	**3×10^{-4}**	**1×10^{-4}**

Notes:
Shaded cells indicate excess cancer risks greater than 1×10^{-6}.

a. Only those COPCs with an excess cancer risk greater than 1×10^{-6} for one or more scenarios are included in this table.
b. Arsenic exposure point concentrations and risk estimates are based on inorganic arsenic.
c. There were no detected values of this COPC for this seafood category. Risk estimate was based on one-half the maximum RL.
d. The higher contribution of cPAHs to overall children's cancer risks is because cPAHs have a mutagenic mode of action and pose greater risks to children than adults. EPA risk assessment procedures account for the greater cancer risks mutagens pose to children.
e. Greater than 50% of the risk associated with this COPC was derived from seafood categories with no detected values.
f. No mussel data were available for this COPC. When the CDI and risk values were calculated, the portion of seafood consumption that had been assigned to mussels was divided proportionally among the remaining consumption categories.
g. Total risk values include the risks associated with all COPCs. Total PCBs is included in the total, and total PCBs TEQ is not included to avoid double-counting risks due to PCBs.
h. Total risk values include the risks associated with all COPCs. Total PCBs TEQ is included in the total, and total PCBs not included to avoid double-counting risks due to PCBs.

API – Asian and Pacific Islander
BHC – benzene hexachloride
CDI – chronic daily intake
COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CT – central tendency
DDT – dichlorodiphenyltrichloroethane
EPA – U.S. Environmental Protection Agency
FS – Feasibility Study
HHRA – human health risk assessment
PCB – polychlorinated biphenyl
RL – reporting limit
RME – reasonable maximum exposure
TEQ – toxic equivalent

Table 3-4b
Estimated Non-cancer Hazards for the HHRA Seafood Consumption Scenarios

COPC[a]	Estimated Non-Cancer Hazard											
	Adult Tribal RME (Tulalip Data)	Adult Tribal CT (Tulalip Data)	Child Tribal RME (Tulalip Data)	Child Tribal CT (Tulalip Data)	Adult Tribal (Suquamish Data)	Adult API RME	Adult API CT	Adult One Meal per Month				
								Benthic Fish	Clam	Crab	Pelagic Fish, Rockfish	Pelagic Fish, Perch
Arsenic[b]	0.4	0.05	0.9	0.1	4	0.4	0.03	0.002	0.08	0.01	0.004	0.009
Cadmium	0.7	0.08	2	0.2	2	0.4	0.03	0.01	0.01	0.09	0.004	0.004
Cobalt	0.6	0.07	1	0.2	4	0.5	0.04	0.01	0.07	0.05	0.02	0.02
Mercury	0.6	0.07	1	0.2	3	0.4	0.04	0.05	0.02	0.09	0.2	0.04
TBT as ion	0.3	0.03	0.7	0.07	4	0.4	0.03	0.007	0.05	0.003	0.2	0.04
Total PCBs[c]	27	3	58	6	214	24	1	13	0.4	0.8	21	8
Total PCBs[d]	8	0.8	17	2	61	7	0.4	4	0.1	0.2	6	2
PCB TEQ[e]	7	0.9	14	2	58	7	0.6	2	0.1	0.3	6	2
Dioxin/furan TEQ[e]	1	0.1	2	0.3	7	0.9	0.07	0.1	0.06	0.07	0.4	0.2
Total TEQ[e]	**8**	**1**	**16**	**2**	**65**	**8**	**0.7**	**2**	**0.2**	**0.4**	**6**	**2**
HIs by Endpoint:												
Hematological endpoint[f]	**0.3**	**0.05**	**0.8**	**0.1**	**2**	**0.2**	**0.02**	**0.01**	**0.02**	**0.04**	**0.03**	**0.02**
Immunological endpoint[g]	**27**	**3**	**59**	**6**	**218**	**24**	**1**	**13**	**0.5**	**0.8**	**21**	**8**
Kidney endpoint[h]	**0.8**	**0.1**	**2**	**0.2**	**3**	**0.5**	**0.04**	**0.02**	**0.02**	**0.1**	**0.01**	**0.01**
Liver endpoint[i]	**0.06**	**0.008**	**0.1**	**0.02**	**0.3**	**0.04**	**0.003**	**0.007**	**0.006**	**0.004**	**0.01**	**0.008**
Neurological endpoint[j]	**28**	**3**	**59**	**6**	**218**	**25**	**1**	**13**	**0.4**	**0.9**	**21**	**8**
Endocrine endpoint[k]	**0.6**	**0.08**	**1**	**0.2**	**4**	**0.5**	**0.04**	**0.01**	**0.08**	**0.05**	**0.02**	**0.02**
Integumentary endpoint[l]	**28**	**3**	**59**	**6**	**219**	**25**	**1**	**13**	**0.5**	**0.8**	**21**	**8**
Digestive system endpoint[m]	**0.5**	**0.06**	**1**	**0.1**	**2**	**0.3**	**0.03**	**0.005**	**0.04**	**0.04**	**0.02**	**0.02**
Developmental endpoint[n]	**10**	**1**	**16**	**2**	**65**	**8**	**0.7**	**4**	**0.2**	**0.5**	**7**	**2**

Notes:

Shaded cells indicate non-cancer HQs greater than 1.

a. Only those COPCs with HQs greater than 1 for one or more scenario are included in this table.
b. Arsenic exposure point concentrations and risk estimates are based on inorganic arsenic.
c. HQ used for the calculation of the immunological, integumentary, and neurological endpoint HIs (Table B.4-1 of the HHRA, Windward 2012b).
d. HQ used for the calculation of the developmental endpoint HI (Table B.4-1 of the HHRA; Windward 2012b).
e. HQs for PCB and dioxin/furan TEQs were not presented in the EW HHRA because no RfD was available to calculate these values. The recently released RfD for 2,3,7,8-TCDD has since been used to calculate the HQs presented in this table. Additional information regarding these new HQs are presented in Attachment 7 to the HHRA (Appendix B of the SRI; Windward and Anchor QEA 2014).
f. Hematological endpoint includes the following chemicals: antimony, selenium, and zinc.
g. Immunological endpoint includes the following chemicals: dibutyltin, total PCBs, and TBT.
h. Kidney endpoint includes the following chemicals: cadmium, molybdenum, and pentachlorophenol.
i. Liver endpoint includes the following chemicals: 1,4-dichlorobenzene, alpha-BHC, total chlordane, total DDTs, dieldrin, heptachlor, heptachlor epoxide, mirex, and pentachlorophenol.
j. Neurological endpoint includes the following chemicals: mercury, total PCBs, and selenium. Neurological effects associated with exposure to lead are discussed in the HHRA, Section B.5.4 (Windward 2012b).
k. Endocrine endpoint includes the following chemicals: antimony and cobalt.
l. Integumentary endpoint includes the following chemicals: arsenic, total PCBs, selenium, and vanadium.
m. Digestive system endpoint includes the following chemicals: chromium and copper.
n. Developmental endpoint includes the following chemicals: mercury, PCBs (the higher of either the total PCB HQ based on the developmental RfD or the PCB TEQ HQ), and dioxin/furan TEQ.

API – Asian and Pacific Islander
BHC – benzene hexachloride
COPC – contaminant of potential concern
CT – central tendency
DDT – dichlorodiphenyltrichloroethane
HHRA – human health risk assessment
HI – hazard index
HQ – hazard quotient
PCB – polychlorinated biphenyl
RfD – reference dose
RME – reasonable maximum exposure
SRI – Supplemental Remedial Investigation
TBT – tributyltin
TEQ – toxic equivalent

Table 3-5

Summary of Estimated Excess Cancer Risks for the RME Seafood Consumption Scenarios

COC	Adult Tribal RME (Tulalip Data) Excess Cancer Risk (% of Total[a])	Adult Tribal RME (Tulalip Data) Percent of Risk by Seafood Consumption Category[b]	Child Tribal RME (Tulalip Data) Excess Cancer Risk (% of Total[a])	Child Tribal RME (Tulalip Data) Percent of Risk by Seafood Consumption Category[b]	Adult API RME Excess Cancer Risk (% of Total[a])	Adult API RME Percent of Risk by Seafood Consumption Category[b]
Arsenic (inorganic)	2×10^{-4} (14%)	82% clams; 8.9% crab EM	4×10^{-5} (13%)	82% clams; 8.9% crab EM	8×10^{-5} (14%)	87% clams; 6.0% mussels
cPAHs (TEQ)	1×10^{-5} (1%)	90% clams	1×10^{-5} (5%)	90% clams	7×10^{-6} (1%)	73% clams; 25% mussels
Total PCBs	1×10^{-3} (76%)	41% benthic fillet; 26% perch; 9.5% crab EM; 9.1% rockfish; 8.5% crab WB; 6.1% clams	2×10^{-4} (73%)	41% benthic fillet; 26% perch; 9.5% crab EM; 9.1% rockfish; 8.5% crab WB; 6.1% clams	4×10^{-4} (76%)	59% rockfish; 16% benthic fillet; 7.3% crab WB; 6.7% clams; 5.5% benthic WB
PCBs (TEQ)	7×10^{-4}	30% benthic fillet; 27% perch; 13% crab WB; 12% crab EM; 11% rockfish; 7.7% clams	1×10^{-4}	30% benthic fillet; 27% perch; 13% crab WB; 12% crab EM; 11% rockfish; 7.7% clams	3×10^{-4}	62% rockfish; 11% benthic fillet; 9.7% crab WB; 7.5% clams; 4.8% benthic WB
Dioxin/furan (TEQ)	1×10^{-4} (7%)	25% clams; 22% crab EM; 18% crab WB; 17% perch; 10% benthic fillet	2×10^{-5} (7%)	25% clams; 22% crab EM; 18% crab WB; 17% perch; 10% benthic fillet	4×10^{-5} (7%)	35% rockfish; 31% clams; 18% crab WB; 7.9% crab EM
Other COCs[c]	3×10^{-5} (2%)	nc	4×10^{-6} (2%)	nc	7×10^{-6} (2%)	nc
Total excess cancer risk and main contributors to the total risk[d]	**1×10^{-3}**	**31% – PCBs in benthic fillet 19% – PCBs in perch 11% – arsenic in clams 7.2% – PCBs in crab EM 6.9% – PCBs in rockfish 6.4% – PCBs in crab WB 18% – other**	**3×10^{-4}**	**30% – PCBs in benthic fillet 18% – PCBs in perch 11% – arsenic in clams 6.9% – PCBs in crab EM 6.6% – PCBs in rockfish 6.1% – PCBs in crab WB 22% – other**	**5×10^{-4}**	**44% – PCBs in rockfish 12% – arsenic in clams 12% – PCBs in benthic fillet 5.6% – PCBs in crab WB 5.1% – PCBs in clams 21% – other**

Notes:

a. Total excess cancer risk includes the risks associated with all COPCs, including total PCBs but excluding PCB TEQ.
b. Seafood consumption categories contributing greater than 5% of the risk for each COC are listed in this table.
c. Together, all other COCs contributed less than 2% to the total excess cancer risk.
d. Seafood consumption category-COC combinations contributing greater than 5% of the total risk are listed separately. All other combinations are included in the “other” category. Total PCBs is included in the total, and total PCBs TEQ is not included to avoid double-counting risks due to PCBs.

API – Asian and Pacific Islander
cPAH – carcinogenic polycyclic aromatic hydrocarbon
COC – contaminant of concern
COPC – contaminant of potential concern
EM – edible meat
HHRA – human health risk assessment
nc – not calculated
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
TEQ – toxic equivalent
WB – whole body

Table 3-6

Estimated Excess Cancer Risks for the HHRA Direct Sediment Exposure Scenarios

COPC	Estimated Excess Cancer Risk					
	Netfishing		Habitat Restoration Worker	Clamming		
	RME	CT		Tribal RME	Tribal – 183 Days per Year	7 Days per Year
Arsenic	3×10^{-6}	7×10^{-7}	5×10^{-7}	1×10^{-5}	2×10^{-5}	4×10^{-7}
cPAHs (TEQ)	3×10^{-7}	2×10^{-8}	1×10^{-7}	2×10^{-6}	3×10^{-6}	8×10^{-8}
Total PCBs	6×10^{-7}	6×10^{-8}	2×10^{-7}	3×10^{-6}	6×10^{-6}	1×10^{-7}
PCBs (TEQ)	3×10^{-7}	4×10^{-8}	5×10^{-8}	1×10^{-6}	2×10^{-6}	3×10^{-8}
Dioxin/furan (TEQ)	6×10^{-7}	1×10^{-7}	NA	1×10^{-6}	2×10^{-6}	4×10^{-8}
Total TEQ excess cancer risk for dioxins/furans and coplanar PCBs	**9×10^{-7}**	**1×10^{-7}**	**NA**	**2×10^{-6}**	**4×10^{-6}**	**7×10^{-8}**
Total excess cancer risk (excluding PCB TEQ)[a]	**5×10^{-6}**	**9×10^{-7}**	**8×10^{-7}**	**2×10^{-5}**	**3×10^{-5}**	**6×10^{-7}**
Total excess cancer risk (excluding total PCBs)[a]	**4×10^{-6}**	**9×10^{-7}**	**7×10^{-7}**	**1×10^{-5}**	**3×10^{-5}**	**6×10^{-7}**

Notes:

Shaded cells indicate excess cancer risks greater than 1×10^{-6}.

a. Total risk values include the risks associated with all COPCs. However, only those COPCs with excess cancer risks greater than 1×10^{-6} for at least one scenario are listed in this table.

COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CT – central tendency
NA – not applicable (not a COPC)
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
TEQ – toxic equivalent

Contaminants with either an estimated excess cancer risk greater than 1 in 1,000,000 (1×10^{-6}) or a non-cancer HQ greater than 1 for at least one RME scenario were selected as COCs for the direct sediment contact exposure pathways. Based on these criteria, four contaminants were identified as COCs for direct sediment contact exposure (Table 3-3): arsenic for both RME scenarios and cPAHs, total PCBs, and total TEQ for clamming RME scenario.[28]

[28] Total TEQ is equal to the sum of PCB TEQ and dioxin/furan TEQ. When excess cancer risks for either PCB TEQ or dioxin/furan TEQ were not independently greater than 1×10^{-6}, the sum of these two chemicals (total TEQ) was identified as a COC if it was greater than this threshold.

3.2.3 Surface Water Exposure Scenarios

In addition to the seafood consumption and direct sediment contact scenarios, exposure to surface water in the EW was assessed for a swimming scenario, for which the exposure parameters were based on the adult swimming scenarios presented in the *King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay* (King County 1999). No RME level of exposure was defined because parameters used for this scenario likely result in significant overestimates of swimming exposure levels for the EW, given that they were developed for areas that include a greater number of recreational access points than the EW, and swimming in the EW will be limited because of a high concentration of large ship and tug boat traffic and cold water temperatures. Therefore, no COCs were identified based on exposure to surface water (Windward 2012b).

The only excess cancer risks that were greater than the 1×10^{-6} threshold were for PCB TEQ for both the high level of exposure (which assumed 2.4 hours of swimming, 24 days per year) and the medium level of exposure (which assumed 1 hour of swimming, 12 days per year) (equal to 9×10^{-6} and 2×10^{-6}, respectively). The total excess cancer risks (which includes all COPCs) for this scenario were also equal to 9×10^{-6} and 2×10^{-6}, respectively. No other COPCs (including total PCBs) had excess cancer risks greater than 1×10^{-6} or non-cancer HQs greater than 1 for any COPC-exposure level combination. As discussed in the EW HHRA (Windward 2012b), the PCB TEQ risk estimate is considered highly uncertain based on both current and anticipated future site use and on the uncertainty associated with the application of the dioxin-like TEQ approach for dermal exposure,[29] which contributed nearly all (over 99%) of PCB TEQ swimming risk (as compared with the incidental ingestion of water).

3.2.4 Sum of Risks for Multiple Exposure Scenarios

Risks for multiple scenarios were summed to represent the possible exposure of a single individual to EW COPCs during different activities. Summed risks (i.e., the sum of risks across pathways) are presented in Table 3-7 for the following multiple exposure scenarios:

- Adult tribal RME netfishing, adult tribal RME seafood consumption, and swimming

[29] The dioxin-like TEQ approach was developed for the consideration of the risk associated with the consumption of tissue (Van den Berg et al. 2006), and its applicability to dermal absorption exposure is uncertain because bioavailability for non-dietary exposures is not well characterized.

- Adult tribal CT netfishing, adult tribal CT seafood consumption, and swimming
- Adult tribal RME clamming, adult tribal RME seafood consumption, and swimming

Table 3-7
Excess Cancer Risk Estimates Across Scenarios

Activity	Excess Cancer Risk[a]
Adult Tulalip RME Combination Scenario	
Netfishing RME	5×10^{-6}
Swimming (medium level of exposure)	2×10^{-6}
Adult tribal RME seafood consumption based on Tulalip data	1×10^{-3}
Total	**1×10^{-3}**
Adult Tulalip CT Combination Scenario	
Netfishing CT	9×10^{-7}
Swimming (low level of exposure)	2×10^{-8}
Adult tribal CT seafood consumption based on Tulalip data	7×10^{-5}
Total	**7×10^{-5}**
Adult RME Clamming Combination Scenario	
Tribal clamming RME (120 days per year)	2×10^{-5}
Swimming (medium level of exposure)	2×10^{-6}
Adult tribal RME seafood consumption based on Tulalip data	1×10^{-3}
Total	**1×10^{-3}**

Notes:
a. For the seafood consumption and sediment exposure scenarios, total excess cancer risk estimates that excluded PCB TEQ were used because these were equal to or higher than total excess cancer risk estimates that excluded total PCBs. For swimming, the total excess cancer risk estimates that excluded total PCBs were used because they were higher than the total that excluded PCB TEQ.
CT – central tendency
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
TEQ – toxic equivalent

When estimated excess cancer risks were rounded to one significant figure, the sums for the three scenario groups above were the same as the estimates for the seafood consumption alone. Overall, swimming had the lowest risk estimates.

This analysis demonstrates that the contributions of netfishing, clamming, and swimming to estimated risks are relatively small in comparison with the contributions of seafood consumption, and it highlights the significance of the seafood consumption exposure pathway for all users of the EW.

3.2.5 Risk Driver COCs for Human Health

Risk drivers were identified from the COC list based on several considerations, including: 1) risk magnitude relative to acceptable risk thresholds (including a consideration of background concentrations, if applicable), 2) percent contribution to the total risk estimate, 3) detection frequency, and 4) other data quality or uncertainty considerations.

A subset of the COCs identified for the seafood consumption RME and direct sediment exposure RME scenarios were identified as risk drivers:

- **Seafood consumption scenarios** – Of the 12 COCs, 3 were identified as risk drivers (cPAHs [TEQ], PCBs,[30] and dioxins/furans [TEQ]).
- **Direct sediment exposure scenarios** – Of the four COCs, one was identified as a risk driver (arsenic).

A summary of risks for each COC, as well as a more detailed discussion of the selection of risk drivers, is presented in Table 3-8. Additional details regarding the selection of risk drivers are presented in Section B.7 of the EW HHRA (Windward 2012b). COCs not selected as risk drivers in the baseline HHRA are evaluated in Section 9 to assess the potential for risk reduction following remedial actions.

Table 3-8
COCs and Risk Drivers Selected for the EW HHRA

COC	Selection as Risk Driver and Summary of Rationale	
	Seafood Consumption RME Scenarios	**Direct Sediment Exposure RME Scenarios**
Arsenic	**NO** – risks greater than the upper end of EPA's acceptable risk range (1×10^{-4}); however, incremental risks were equal to or less than 1×10^{-6} because concentrations are similar to or lower than those in samples collected from background areas	**YES** – risk greater than the 10^{-6} threshold, percent contribution to the total risk (63% to 67%), and high detection frequency (70%)

[30] The consideration of PCBs as a risk driver is intended to account for both total PCBs and PCB (TEQ). It should be noted that risks for total PCBs were higher than those for PCB (TEQ) for all scenarios.

Table 3-8
COCs and Risk Drivers Selected for the EW HHRA

COC	Selection as Risk Driver and Summary of Rationale: Seafood Consumption RME Scenarios	Selection as Risk Driver and Summary of Rationale: Direct Sediment Exposure RME Scenarios
Cadmium	**NO** – HQ equal to 2 for the child tribal RME scenario based on Tulalip data; but considerable uncertainty is associated with this scenario, and HQs for total PCBs were over an order of magnitude higher	**NA** – not a COPC
cPAHs (TEQ)	**YES** – risks within EPA's acceptable risk range (up to 1×10^{-5}), percent contribution to the total risk (1% to 5%), and high detection frequency (71%)	**NO** – risks were only slightly greater than the 1×10^{-6} threshold
Total PCBs	**YES** – risks greater than the upper end of EPA's acceptable risk range (1×10^{-4}), percent contribution to the total risk (73% to 75%), and high detection frequency (98%)	**NO** – risks were only slightly greater than the 1×10^{-6} threshold
Pentachlorophenol[a]	**NO** – risk slightly greater than the 1×10^{-6} threshold for one of the three RME scenarios; contribution to the total excess cancer risk was less than 1%, and COC was detected in less than 4% of EW samples	**NA** – not a COPC
Pesticides[a,b]	**NO** – risks less than 1×10^{-5}, and each COC contributed less than 1% to the total excess cancer risk (combined contribution was less than 1.5% of the total)	**NA** – not a COPC
Dioxin/furan (TEQ)	**YES** – risks equal to the upper end of EPA's acceptable risk range (1×10^{-4}) and high detection frequency (100%)	**NO** – not a COC[c]
Total TEQ (sum of PCB TEQ and dioxin/furan TEQ)	**NA**[d]	**NO** – risks were only slightly greater than the 1×10^{-6} threshold

Notes:
a. Many of the analytical results upon which exposure point concentrations (EPCs) were based consisted of non-detects.
b. Five pesticides were identified as COCs for the seafood consumption scenarios: alpha-BHC, dieldrin, total chlordane, heptachlor epoxide, and mirex. It should also be noted that there is no evidence of historical use or manufacture of these pesticides in the EW.
c. See Section 6.3.3 of the SRI (Windward and Anchor QEA 2014) for information regarding the selection of COCs for the direct sediment exposure scenarios.
d. Total TEQ was considered only when neither PCB TEQ nor dioxin/furan TEQ independently qualified as a COC.

BHC – benzene hexachloride
COC – contaminant of concern
NA – not applicable
PCB – polychlorinated biphenyl

COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
EW – East Waterway
RME – reasonable maximum exposure
SRI – Supplemental Remedial Investigation
TEQ – toxic equivalent

3.3 Risk-based Threshold Concentrations

For the EW, RBTCs are concentrations of risk driver COCs in sediment or tissue that are associated with specific risk estimates and exposure pathways. Cleanup of sediment to concentrations at or below a specific RBTC is predicted to be protective for the particular risk driver COCs, based on the exposure assumptions of the baseline risk assessments (Windward 2012a, 2012b). RBTCs for tissue and sediment were presented in Section 8 of the SRI (Windward and Anchor QEA 2014). Sediment RBTCs are used in this FS along with other information to establish PRGs (as presented in Section 4).

RBTCs for the human health risk driver COCs were calculated at three different excess cancer risk levels and for HQs equal to 1 (when the non-cancer hazard was greater than 1 in the HHRA) for both the direct contact with sediment scenarios (i.e., netfishing and tribal clamming) and the seafood consumption scenarios. The equations used to calculate the sediment RBTCs are based on the risk equations used in the baseline HHRA (Windward 2012b). RBTCs for ecological receptors were either based on TRVs used in the ERA or were based on Washington State SMS numeric sediment criteria (e.g., SQS).

3.3.1 RBTCs for Ecological Receptors

Risk driver COCs for ecological receptors include total PCBs for English sole and brown rockfish, TBT for benthic invertebrates, and 29 SMS contaminants with concentrations that exceeded the SQS in one or more surface sediment samples. The following describes the derivation of sediment RBTCs for these ecological risk driver COCs:

- **Total PCB RBTCs for fish** – Because of uncertainties in the study used to develop the tissue TRV for fish exposure to total PCBs, two tissue TRVs (520 and 2,640 µg/kg wet weight [ww]) were evaluated in the ERA (Windward 2012a), both of which were considered as tissue RBTCs. Sediment RBTCs for fish were then derived using the calibrated food web model (FWM) for the EW, as described in Section 8 of the SRI (Windward and Anchor QEA 2014). The sediment RBTC values ranged from 39 to greater than 470 µg/kg ww, depending on the tissue RBTC and species (Table 3-9).

Sediment RBTCs of greater than 470 µg/kg dw indicate that even under current conditions in the EW,[31] average tissue concentrations are estimated to be less than the tissue RBTC. This is consistent with the fact that average tissue concentrations in both species are less than the tissue TRV of 2,640 µg/kg ww. Only 4 out of the 15 individual rockfish samples and 7 out of 13 English sole whole-body composite tissue samples exceeded the tissue TRV of 2,640 µg/kg ww.

- **TBT RBTC for benthic invertebrates** – A sediment RBTC for TBT for the protection of the benthic invertebrate community was calculated using a biota-sediment accumulation factor (BSAF) developed using benthic invertebrate tissue and co-located sediment TBT and TOC concentrations from the EW. The sediment RBTC for TBT was 7.5 mg/kg OC, which results in a range of dry-weight sediment concentrations of 75 to 150 µg/kg dw for TOC values from 1% to 2%, which are typical TOC values for EW sediment.
- **RBTCs for SMS chemicals for benthic invertebrates** – Sediment RBTCs were set to the SQS and CSL sediment criteria from the SMS for the protection of benthic invertebrates (see Table 3-1 for these SMS values).

The sediment RBTCs derived for the risk driver COCs identified in the ERA are summarized in Table 3-9.

3.3.2 Sediment RBTCs for HHRA Direct Sediment Exposure Scenarios

Sediment RBTCs for the human health direct sediment contact exposure scenarios were calculated for arsenic for the three excess cancer risk levels (1×10^{-6}, 1×10^{-5}, and 1×10^{-4}; Table 3-10). Sediment RBTCs were not calculated for non-cancer hazards (at an HQ of 1) because all HQs were less than or equal to 1 for the RME scenarios in the HHRA (Windward 2012b).

3.3.3 Tissue RBTCs for HHRA Seafood Consumption Scenarios

Tissue RBTCs associated with the three RME seafood consumption scenarios were calculated for all three risk driver COCs (i.e., total PCBs, cPAHs, and dioxins/furans) for the three

[31] A sediment SWAC of 470 µg/kg dw was used in the FWM because it reflected the most current sediment interpolation at the time of model calibration.

Table 3-9
Sediment RBTCs for Ecological Risk Driver COCs

Risk Driver	Ecological Receptor	Sediment RBTC
Total PCBs	English sole	100 µg/kg dw (at tissue TRV of 520 µg/kg ww); >470 µg/kg dw[a] (at tissue TRV of 2,640 µg/kg ww)
	brown rockfish	39 µg/kg dw (at tissue TRV of 520 µg/kg ww); 458 µg/kg dw (at tissue TRV of 2,640 µg/kg ww)
TBT	benthic invertebrates	7.5 mg/kg OC, or 75 to 150 µg/kg dw (assuming 1 to 2% TOC)
29 SMS chemicals[b]	benthic invertebrates	SQS and CSL sediment criteria

Notes:
a. Sediment RBTC of >470 µg/kg dw indicate that under current conditions in the EW (the SWAC used in the calibrated FWM is equal to 470 µg/kg dw), average tissue concentration is estimated to be less than the tissue RBTC.
b. The 29 SMS chemicals identified as risk drivers are arsenic, cadmium, mercury, zinc, acenaphthene, anthracene benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo (a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3,-c,d)pyrene, phenanthrene, pyrene, total benzofluoranthenes, HPAH, LPAH, bis(2-ethylhexyl) phthalate, butyl benzyl phthalate, di-n-butyl phthalate, 1,4-dichlorobenzene, 2-methylnaphthalene, 2,4-dimethylphenol, dibenzofuran, n-nitrosodiphenylamine, phenol, and total PCBs.

µg/kg – micrograms per kilogram
COC – contaminant of concern
CSL – cleanup screening level
dw – dry weight
FWM – food web model
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
OC – organic carbon
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SWAC – spatially-weighted average concentration
TBT – tributyltin
TOC – total organic carbon
TRV – toxicity reference value
ww – wet weight

Table 3-10
Sediment RBTCs for Human Health Risk Driver COC for RME Direct Sediment Exposure Scenarios

Risk Driver COC	Unit	Exposure Scenario	Sediment RBTCs: 10^{-6} (1 in 1,000,000) Risk Level	10^{-5} (1 in 100,000) Risk Level	10^{-4} (1 in 10,000) Risk Level
Arsenic	mg/kg dw	tribal clamming	1.3	13	130
		netfishing	3.7	37	370

Notes:
RBTCs were not calculated for non-cancer endpoints because estimated HQs were all < 1.

µg – micrograms
COC – contaminant of concern
dw – dry weight
mg/kg – milligrams per kilogram
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure

excess cancer risk levels, and for total PCBs and dioxin/furan TEQ for a non-cancer HQ of 1 (Table 3-11). Tissue RBTCs associated with human seafood consumption scenarios were calculated in the SRI (Windward and Anchor QEA 2014) using rearrangements of the risk equations in the baseline HHRA (Windward 2012b); the risk equations and parameters used to calculate the tissue RBTCs are presented in Table 3-12. To derive the tissue RBTCs, these equations were solved for the concentration in seafood for a given target risk level using scenario-specific parameters (e.g., ingestion rates, body weights). As shown in Table 3-11, the tissue RBTCs for the adult tribal RME scenario based on Tulalip data were lower than those for the other RME scenarios for a given risk threshold for each risk driver COC.

Table 3-11
Ingestion-weighted Tissue RBTCs for the Human Health RME Seafood Consumption Scenarios

Risk Driver	Target Risk	Ingestion-weighted Tissue RBTC[a]			
		Excess Cancer Risk			Non-Cancer Hazard
		1×10^{-6}	1×10^{-5}	1×10^{-4}	HQ = 1
cPAHs[b] (µg TEQ/kg ww)	Adult Tribal RME (Tulalip Data)	0.84	8.4	84	NA
	Child Tribal RME (Tulalip Data)	0.85[c]	8.5[c]	85[c]	NA
	Adult API RME	2.9	29	290	NA
Dioxin/furan[d] (ng TEQ/kg ww)	Adult Tribal RME (Tulalip Data)	0.0056	0.056	0.56	NA[e]
	Child Tribal RME (Tulalip Data)	0.030	0.30	3.0	8.2
	Adult API RME	0.019	0.19	1.9	NA[e]
Total PCBs (µg/kg ww)	Adult Tribal RME (Tulalip Data)	0.42	4.2	42	17
	Child Tribal RME (Tulalip Data)	2.3	23	230	7.8
	Adult API RME	1.4	14	140	24

Notes:
a. Tissue RBTCs associated with human seafood consumption scenarios were calculated in the SRI (Windward and Anchor QEA 2014) using rearrangements of the risk equations in the baseline HHRA (Windward 2012b).
b. cPAHs are presented as benzo(a)pyrene TEQs.
c. Because of the potential for increased susceptibility of children to carcinogens with mutagenic activity, as described in EPA guidance (2005), the risk estimate for children for cPAHs is based on dose adjustments across the 0-to-6-year age range of children (see Section B.5.1 of the HHRA for more information).
d. Dioxins/furans are presented as 2,3,7,8-TCDD mammalian TEQs.
e. An RBTC for dioxin/furan TEQ was only calculated for the child tribal RME scenario based on Tulalip data because it was the only RME scenario with an HQ > 1 for dioxin/furan TEQ.

µg – micrograms
API – Asian and Pacific Islanders
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
EPA – U.S. Environmental Protection Agency
NA – not applicable
ng – nanograms
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure

HHRA – human health risk assessment
HQ – hazard quotient
kg – kilograms
mg – milligrams
SRI – Supplemental Remedial Investigation
TCDD – tetrachlorodibenzo-*p*-dioxin
TEQ – toxic equivalent
ww – wet weight

Table 3-12

Equations and Parameter Values for the Calculation of Tissue RBTCs

RBTC equation for carcinogenic effects:			**RBTC equation for non-carcinogenic effects:**		
$Tissue\ RBTC = \frac{TR}{\left(\left[\frac{IR \times FC \times EF \times ED \times CF}{BW \times AT_c}\right] \times SF\right)}$			$Tissue\ RBTC = \frac{THQ}{\left(\left[\frac{IR \times FC \times EF \times ED \times CF}{BW \times AT_{nc}}\right] \times \frac{1}{RfD}\right)}$		
			Parameter Values[a]		
Parameter Name	**Acronym**	**Unit**	**Adult Tribal RME (Tulalip Data)**	**Child Tribal RME (Tulalip Data)**	**Adult API RME**
Risk-based threshold concentration	RBTC	mg/kg ww	see Table 3-11 for calculated RBTCs		
Target excess cancer risk	TR	unitless	10^{-6}, 10^{-5}, 10^{-4}	10^{-6}, 10^{-5}, 10^{-4}	10^{-6}, 10^{-5}, 10^{-4}
Target HQ	THQ	unitless	1	1	1
Ingestion rate	IR	g/day	97.5	39.0	51.5
Fraction from contaminated site	FC	unitless	1	1	1
Exposure frequency	EF	days	365	365	365
Exposure duration	ED	years	70	6	30
Conversion factor	CF	kg to g	0.001	0.001	0.001
Body weight	BW	kg	81.8	15.2	63
Averaging time, cancer	AT_c	days	25,550	25,550	25,550
Averaging time, non-cancer	AT_{nc}	days	25,550	2,190	10,950
Slope factor	SF	$(mg/kg\text{-}day)^{-1}$	toxicity values are contaminant-specific (Total PCBs = 2; cPAH TEQ = 1; dioxin/furan TEQ = 150,000)		
Reference dose	RfD	mg/kg-day	toxicity values are contaminant-specific (Total PCBs = 0.00002; dioxin/furan TEQ = 7×10^{-10})		

Notes:
a. Parameter values are the same as those used in the LDW HHRA (Windward 2007a).

API – Asian and Pacific Islanders
cPAH – carcinogenic polycyclic aromatic hydrocarbon
g – gram
HHRA – human health risk assessment
HQ – hazard quotient
kg – kilogram
LDW – Lower Duwamish Waterway
mg – milligram
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
TEQ – toxic equivalent

The tissue RBTCs for the seafood consumption scenarios presented in Table 3-11 represent the ingestion-weighted average concentrations in tissue that correspond to a certain risk threshold for each scenario. For example, the RBTC for total PCBs for the adult tribal RME seafood consumption scenario based on Tulalip data is 4.2 µg/kg ww at the 1×10^{-5} excess cancer risk level. Thus, the consumption of 97.5 grams per day (g/day; the daily ingestion rate for the adult tribal RME scenario based on Tulalip data) of any tissue type with a total PCB concentration of 4.2 µg/kg ww for 70 years would result in a 1×10^{-5} excess cancer risk. The consumption of numerous types of seafood, such as crabs, clams, and fish (as specified in the exposure parameters for the adult tribal RME scenario based on Tulalip data), would also result in a 1×10^{-5} excess cancer risk as long as the ingestion-weighted average of the various tissue concentrations was 4.2 µg/kg ww. Thus, the tissue RBTCs presented in this section are not directly comparable with single species concentrations (e.g., the non-urban Puget Sound tissue concentrations presented in Section 7 of the SRI [Windward and Anchor QEA 2014]).

3.3.4 Sediment RBTCs for HHRA Seafood Consumption Scenarios

Sediment RBTCs for the human health seafood consumption exposure scenarios represent the sediment concentrations at which tissue concentrations equate to the targeted risk level. Thus, these RBTCs require developing a relationship between concentrations in sediment and tissue, as described below for each risk driver COC.

- **Total PCB sediment RBTCs** – A FWM calibrated for the EW (see Appendix C of the SRI; Windward and Anchor QEA 2014) was used to estimate the relationship between sediment and tissue concentrations for total PCBs, and to calculate sediment RBTCs. A range of RBTCs was calculated for each seafood exposure scenario using best estimate, upper bound, and lower bound parameter sets in the FWM. Sediment RBTCs for PCBs at the 1 in 1 million (1×10^{-6}) and 1 in 100,000 (1×10^{-5}) excess cancer risk levels and non-cancer risk of HQ = 1 for the tribal RME (adult and child) scenario could not be calculated; the contribution of total PCBs from water alone was high enough to result in excess cancer risks or non-cancer risk above those risk levels even in the absence of any contribution from sediment; the sediment RBTCs for these scenarios are expressed as "< 1" µg/kg dw in Table 3-13). At the 1 in 10,000 (1×10^{-4}) excess cancer risk level, sediment RBTCs for total PCBs ranged from 2 to 250 µg/kg dw for the three RME scenarios (Table 3-13). These sediment RBTCs for total PCBs are lower than the current

SWAC of total PCBs in the EW (approximately 470 µg/kg dw). It should be noted that sediment RBTCs for the lower risk levels (i.e., 1×10^{-5} and 1×10^{-6}) are especially difficult to quantify for several reasons. First, the FWM was calibrated for baseline conditions (i.e., a sediment concentration of 470 µg/kg PCBs), not post-remedy conditions that would be associated with lower concentrations and lower risk levels. The greater the difference between baseline and post-remedy conditions, the greater the uncertainty in the model application. Second, at the very low sediment total PCB concentrations associated with the low risk levels, the assumed total PCB concentration in water becomes increasingly important in affecting the modeling results, and the assumed post-remedy water value is also uncertain.

- **Dioxin/furan sediment RBTCs** – Dioxin/furan sediment RBTCs were developed using site-specific BSAFs for four species (English sole, brown rockfish, shiner surfperch, and crab), which were based on empirical data collected from the EW. BSAF values were calculated for a subset of four individual dioxin/furan congeners that were selected because they were the congeners that had the greatest contributions to the dioxin/furan TEQ values in tissues. Because BSAFs are specific to individual receptor species, it was necessary to convert the ingestion-weighted average tissue RBTCs presented in Table 3-11 to species-specific RBTCs. The main assumptions required for these calculations were the relative ingestion rates for the various items in the market basket diet and the relative tissue contaminant concentrations among the food items. Because both of these factors may change in the future, it is important to recognize that there is considerable uncertainty associated with the dioxin/furan sediment RBTCs based on these species-specific tissue RBTCs. At the 1×10^{-6} target risk level, the sediment RBTCs for the RME scenarios were less than 1 ng TEQ/kg dw (Table 3-13). At the 1×10^{-4} target risk level, sediment RBTCs for dioxin/furan TEQ ranged from 18 to 94 ng TEQ/kg dw for the three RME scenarios (Table 3-13). Details regarding the derivation of these sediment RBTCs are presented in Section 8 and Appendix C of the SRI (Windward and Anchor QEA 2014).
- **cPAH sediment RBTCs** – For cPAHs, 73% to 90% of the risk associated with seafood consumption for the RME scenarios is attributable to the consumption of clams. Thus, because of the importance of clam consumption in the cPAH TEQ risk estimate, the clam tissue-to-sediment relationship was evaluated to assess the potential for calculating sediment RBTCs. As discussed in Section 8.3.3 of the SRI (Windward and

Anchor QEA 2014), the clam tissue-to-sediment relationship for cPAHs in the EW is too uncertain to develop a sediment RBTC based on clam consumption. Variables other than localized sediment concentrations are likely to be important factors in determining tissue concentrations of cPAHs, based on the filter-feeding behavior of clams and, thus, any potential effect of sediment remediation on concentrations of cPAHs in clam tissue is highly uncertain. Long-term clam tissue monitoring following sediment remediation and source control will be needed to determine whether (and to what extent) decreases in cPAH concentrations in sediment result in decreases in cPAH concentrations in clam tissue.

Table 3-13
Sediment RBTCs for the HHRA RME Seafood Consumption Scenarios

Excess Cancer Risk Level[a]	Sediment RBTCs for the RME Scenarios		
	Adult Tribal RME (Tulalip data)	Child Tribal RME (Tulalip data)	Adult API RME
Total PCBs (µg/kg dw)[b]			
1×10^{-4}	2	250	100
1×10^{-5}	<1[c]	<1[c]	<1[c]
1×10^{-6}	<1[c]	<1[c]	<1[c]
HQ = 1	<1[c]	<1[c]	<1[c]
Dioxin/Furan TEQ (ng TEQ/kg dw)[d]			
1×10^{-4}	18	94	48
1×10^{-5}	1.8	9.4	4.8
1×10^{-6}	0.18	0.94	0.48
HQ = 1	n/c[e]	8.2	n/c[e]

Notes:

a. The clam tissue-to-sediment relationship for cPAHs in the EW is too uncertain to develop sediment RBTCs based on clam consumption (Section 3.3.4).
b. The RBTC was derived using the FWM parameter set that resulted in the closest match between empirical data and model estimates for all species.
c. Value could not be calculated because contribution from water alone resulted in estimated tissue concentrations greater than the applicable risk level, even in the absence of any contribution from sediment.
d. The RBTC is the mean of the RBTCs derived using site-specific BSAFs and tissue RBTCs derived for English sole, rockfish, shiner surfperch, and clams based on the market basket allocations for these species (see Section 8 of the SRI; Windward and Anchor QEA 2014).
e. An RBTC for dioxin/furan TEQ was only calculated for the child tribal RME scenario based on Tulalip data because it was the only RME scenario with an HQ > 1 for dioxin/furan TEQ.

µg/kg – micrograms per kilogram
API – Asian and Pacific Islander
BSAF – biota-sediment accumulation factor
n/c – not calculated
ng – nanograms
PCB – polychlorinated biphenyl

dw – dry weight
FWM – food web model
HHRA – human health risk assessment
HQ – hazard quotient
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
SRI – Supplemental Remedial Investigation
TEQ – toxic equivalent

3.4 Key Findings of the Baseline Risk Assessments

Key findings for the baseline ERA (Windward 2012a) are as follows:

- **Ecological risk driver COCs** – Risk driver COCs for ecological receptors include total PCBs for English sole and brown rockfish, TBTs for benthic invertebrates, and 29 SMS contaminants with concentrations that exceeded the SQS in one or more surface sediment samples.
- **Sediment RBTCs for ecological receptors** – Sediment RBTCs for the benthic invertebrate community were established at the SQS and CSL criteria of the SMS. Sediment RBTCs were derived using tissue TRVs and the calibrated EW FWM for fish and total PCBs, and were derived using site-specific BSAFs for TBT and benthic invertebrates (Table 3-9).
- **Potential for adverse effects in the benthic invertebrate community** – Comparison of sediment chemistry and site-specific toxicity test results with SMS indicated that no adverse effects on benthic invertebrates living in intertidal and subtidal sediments are predicted for approximately 38% of the EW area (i.e., the 59 acres in which contaminant concentrations were less than or equal to SQS chemical criteria or sediment was non-toxic according to SQS biological effects criteria). Minor adverse effects are predicted in approximately 23% of the EW area (36 acres), which had contaminant concentrations or biological effects in excess of the CSL values. The remaining 39% of the EW area (60 acres) had contaminant concentrations or biological effects between the SQS and CSL values, indicating the potential for minor adverse effects to benthic invertebrate communities.

Key findings for the baseline HHRA (Windward 2012b) are as follows:

- **Summary of risks** – The highest risks to people were associated with the consumption of resident seafood, including fish, crabs, and clams (Tables 3-4a and 3-4b). Lower risks were associated with activities that involve direct contact with sediment or surface water, such as clamming, netfishing, habitat restoration, or swimming (Table 3-6).
- **Risk driver COCs** – Arsenic was identified as a risk driver COC for human health based on direct sediment exposure, and PCBs, cPAHs, and dioxins/furans were

identified as risk driver COCs for human health based on seafood consumption (Tables 3-8 and 3-14). Arsenic was not identified as a risk driver for seafood consumption because, although total risk posed by arsenic was greater than the upper end of EPA's acceptable risk range, incremental risks were equal to or less than 1×10^{-6}.[32] This is because concentrations are similar to, or lower than, those in samples collected from background areas.

- **Sediment RBTCs for RME direct sediment contact scenarios** – Sediment RBTCs were calculated for arsenic (the risk driver COC) at all three excess cancer risk levels (Table 3-10).
- **Tissue RBTCs for RME seafood consumption scenarios** – Tissue RBTCs were calculated for PCBs, cPAHs, and dioxins/furans (the three risk driver COCs) at the three excess cancer risk levels. Tissue RBTCs were also calculated for PCBs and dioxins/furans based on the non-cancer threshold (Table 3-11).
- **Sediment RBTCs for the RME seafood consumption scenarios**:
  - **Total PCBs** – For total PCBs, sediment RBTCs were developed using a food web model for the EW and ranged from 2 to 250 µg/kg dw for the 1 in 10,000 (1×10^{-4}) excess cancer risk level for the three RME scenarios (Table 3-13). RBTCs for the 10^{-5} and 10^{-6} risk levels and the non-cancer RBTC for total PCBs for the RME seafood consumption scenarios were less than 1 µg/kg dw.
  - **Dioxins/furans** – For dioxins/furans, sediment RBTCs were estimated for each excess cancer risk level using site-specific BSAFs for four species (English sole, brown rockfish, shiner surfperch, and crab) and species-specific tissue RBTCs. Sediment RBTCs for the three RME scenarios were less than 1 ng TEQ/kg dw at the 1×10^{-6} target risk level and ranged from 18 to 94 ng TEQ/kg dw at 1×10^{-4} target risk level (Table 3-13).
  - **cPAHs** – For cPAHs, 73% or more of the risk associated with seafood consumption is attributable to the consumption of clams. Because the clam tissue-to-sediment contaminant concentration relationships in the SRI data were too uncertain to

[32] Details regarding the incremental risk evaluation can be found in Section B.5.5.1.2 of the East Waterway HHRA (Windward 2012b). This section discusses both the background arsenic dataset as well as the calculation of the incremental risks (i.e., the difference between risks estimates for the EW and those calculated for background areas).

support developing quantitative sediment RBTCs for cPAHs, sediment RBTCs were not derived.

The risk screening process used to identify COPCs, COCs, and risk drivers for human health and ecological receptors is summarized in Table 3-14. The COCs not selected as risk drivers are evaluated in Section 9 to assess the potential for risk reduction following remedial actions.

Table 3-14
Summary of Risk Screening and Identification of COCs and Risk Drivers

Chemical Category	Contaminants				
	Human Health Seafood Consumption	Human Health Direct Sediment Contact	Human Health Direct Surface Water Contact	Benthic Invertebrate Community	Other Ecological Receptors
STEP 1 – Conduct conservative risk-based screening to identify COPCs *Ecological: COPCs are contaminants with maximum exposure concentrations greater than TRVs or SQS.* *Human Health: COPCs are contaminants with maximum sediment or tissue concentrations greater than screening criteria.*					
COPCs	54 COPCs, including metals, PAHs, PCBs, dioxins/furans, organochlorine pesticides, and other SVOCs	**Netfishing** – 9 COPCs **Clamming** – 11 COPCs **Habitat Restoration** – 5 COPCs (COPCs included metals, PCBs, cPAHs, dioxins/furans, and other contaminants)	**Swimming** – 14 COPCs, including metals, PCBs, PAHs, and other SVOCs	**Benthic invertebrates** – 30 COPCs including metals, PAHs, PCBs, phthalates, and other SVOCs based on detected exceedance of SQS in surface sediment at one or more locations; total DDTs based on DMMP exceedance; naphthalene; TBT	**Crabs** – arsenic, cadmium, copper, mercury, zinc, TBT, and total PCBs **Fish** – arsenic, cadmium, chromium, copper, mercury, vanadium, total PCBs, TBT, benzo(a)pyrene, beta-endosulfan **Birds** –mercury, total PCBs, PCB TEQ, total TEQ **Mammals** – mercury, selenium, total PCBs, PCB TEQ, total TEQ
STEP 2 – Compare risk estimates to thresholds to identify COCs for both human health and ecological receptors *Ecological: COCs are contaminants with LOAEL-based HQs greater than or equal to 1.0 or greater than the SQS for benthic invertebrates.* *Human Health: COCs are contaminants with excess cancer risk estimates greater than 1×10^{-6} or an HQ greater than 1 for any RME scenario.*					
COCs	Arsenic, cadmium, cPAHs, PCP, PCBs, alpha-BHC, dieldrin, total chlordane, heptachlor epoxide, mirex, dioxins/furans	**Netfishing**[a] – arsenic **Clamming** –arsenic, cPAHs, PCBs, total TEQ	na	**Benthic invertebrates** – 30 COCs (based on SQS); total DDTs (based on DMMP); naphthalene; TBT	**Crabs** – cadmium, copper, and zinc **Fish** – cadmium, copper, vanadium, TBT, total PCBs

Table 3-14

Summary of Risk Screening and Identification of COCs and Risk Drivers

Chemical Category	Contaminants				
	Human Health Seafood Consumption	Human Health Direct Sediment Contact	Human Health Direct Surface Water Contact	Benthic Invertebrate Community	Other Ecological Receptors
STEP 3 – Apply weight-of-evidence approach to identify risk drivers *Ecological: Selection based on risk estimates, uncertainties discussed in the baseline ERA, and background considerations.* *Human Health: Selection based on magnitude of risk, relative percentage of total human health risk posed by the COC, and background considerations.*					
Risk drivers[b]	Total PCBs, cPAHs, dioxins/furans	Arsenic[c]	na	**Benthic invertebrates** – 29 COCs above SQS[d]; TBT	**Fish (English sole and brown rockfish)** – total PCBs

Notes:

a. As noted in Table 3-3, cPAH TEQ was identified as a COC for netfishing in the HHRA. Subsequent to the HHRA, the cancer slope factor was updated in EPA's IRIS database for benzo[*a*]pyrene. This reduced the cPAH TEQ risks calculated in this FS as compared with those in the HHRA (Windward 2019). The updated cPAH TEQ netfishing risks for the RME scenario are below 1×10^{-6} , meaning cPAH TEQ is not a COC for the netfishing scenario. Thus, cPAH TEQ is not included in analyses for the netfishing scenario in the remainder of the FS.

b. COCs that were not selected as risk drivers are evaluated to assess the potential for risk reduction following remedial actions; this evaluation is presented in Section 9.

c. As noted in Table 3-3, cPAH TEQ was identified as a risk driver for clamming and netfishing in the HHRA. Subsequent to the HHRA, the cancer slope factor was updated in EPA's IRIS database for benzo[*a*]pyrene. This reduced the cPAH TEQ risks calculated in this FS as compared with those in the HHRA (Windward 2019). Based on the updated cPAH TEQ risks for the RME scenarios,cPAH TEQ is not a COC (and thus not a risk driver) for netfishing direct contact scenario and cPAHs is not a risk driver for the clamming direct contact scenario. Thus, cPAH TEQ is not included in analyses for direct contact scenarios in the remainder of the FS.

d. The 29 SMS chemicals identified as risk drivers are arsenic, cadmium, mercury, zinc, acenaphthene, anthracene benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo (a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3,-c,d)pyrene, phenanthrene, pyrene, total benzofluoranthenes, HPAH, LPAH, bis(2-ethylhexyl) phthalate, butyl benzyl phthalate, di-n-butyl phthalate, 1,4-dichlorobenzene, 2-methylnaphthalene, 2,4-dimethylphenol, dibenzofuran, n-nitrosodiphenylamine, phenol, and total PCBs.

BHC – benzene hexachloride
COC – contaminant of concern
COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DDT – dichlorodiphenyltrichloroethane
DMMP – Dredged Material Management Program
ERA – ecological risk assessment
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
HQ – hazard quotient
LOAEL – lowest-observed-adverse-effect level
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
PCP – pentachlorophenol
RBC – risk-based concentration
RME – reasonable maximum exposure
RSL – regional screening level
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SVOC – semivolatile organic compound
TBT – tributyltin
TEQ – toxic equivalent
TRV – toxicity reference value

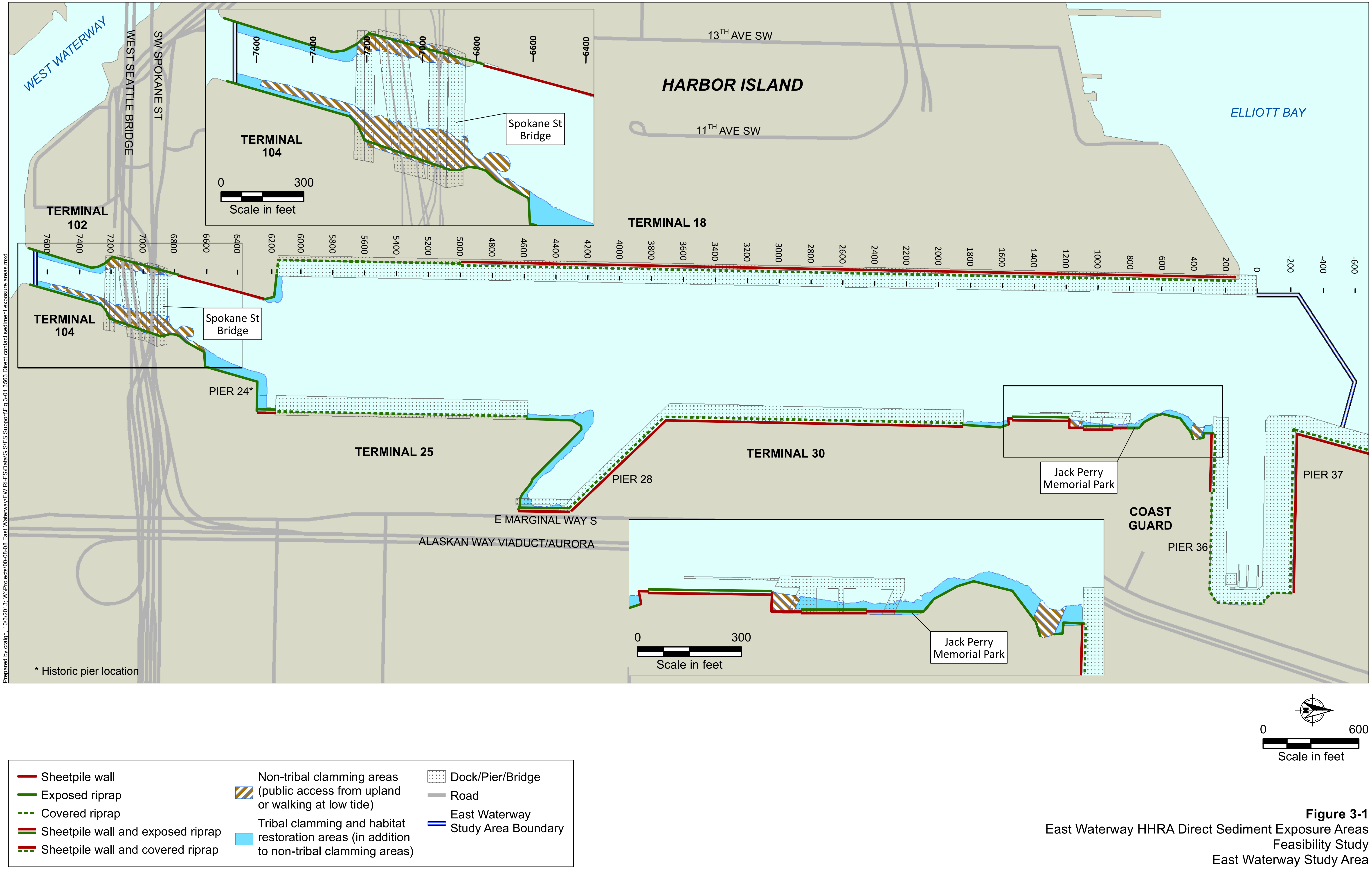


Figure 3-1
East Waterway HHRA Direct Sediment Exposure Areas
Feasibility Study
East Waterway Study Area

4 REMEDIAL ACTION OBJECTIVES AND PRELIMINARY REMEDIATION GOALS

This section identifies narrative RAOs and numerical PRGs for cleanup of the EW. RAOs for the EW describe goals for the protection of human health and the environment (EPA 1999a). PRGs are the contaminant endpoint concentrations or risk levels associated with each RAO that are believed to be sufficient to protect human health and the environment based on available site information (EPA 1997b).

The step of identifying narrative RAOs provides a transition between the findings of the human health and ecological risk assessments and development of remedial alternatives in the FS. The RAOs pertain to the specific exposure pathways and receptors evaluated in the risk assessments and for which unacceptable risks were identified.

RAOs are developed herein for cleanup of contaminated sediment in the EW. Surface water is also a medium of concern because risks to human health and ecological receptors are created by hazardous substances in the water column in addition to those in sediments. However, no active remedial measures are anticipated solely for the water column. Nevertheless, significant improvements in surface water quality are expected following sediment cleanup and implementation of upland source control measures. Further, water quality monitoring will be part of long-term monitoring for the site.

PRGs are intended to protect human health and the environment and to comply with ARARs for specific contaminants (EPA 1991a). For the EW, PRGs are numerical concentrations or ranges of concentrations in sediment that protect a particular receptor from exposure to a risk driver COC by a specific pathway. The PRGs are expressed as sediment concentrations for the identified risk driver COCs because the alternatives in this FS address cleanup of contaminated sediments. Although ARARs are identified in this FS for surface water, PRGs are not developed for surface water because actions to directly address water quality are not included among the FS alternatives.

4.1 Applicable or Relevant and Appropriate Requirements

CERCLA Section 121(d) requires remedial actions to comply with (or formally waive) ARARs, which are defined as any legally applicable or relevant and appropriate standard, requirement, criterion, or limitation under any federal environmental law, or promulgated under any state environmental or facility siting law that is more stringent than the federal requirements. This subsection identifies ARARs for cleanup of the EW. Section 9 of this document evaluates whether the remedial alternatives developed for cleanup of the EW comply with these ARARs.

The NCP (40 CFR 300.5) defines applicable requirements as the more stringent among those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstances found at a CERCLA site. A requirement may not be applicable, but nevertheless may be relevant and appropriate.

Table 4-1 lists and summarizes ARARs identified for the EW OU. Some ARARs prescribe minimum numerical requirements or standards for specific media such as sediment, surface water, and groundwater. Other ARARs place requirements or limitations on actions that may be undertaken as part of a remedy.

Some ARARs contain numerical values or methods for developing such values. These ARARs establish minimally acceptable amounts or concentrations of hazardous substances that may remain in or be released to the environment, or minimum standards of effectiveness and performance expectations for the remedial alternatives. RBTCs based on risks to human health or the environment may dictate setting more stringent standards for remedial action performance, but they cannot be used to relax the minimum legally prescribed standards in ARARs (EPA 1991a). The rest of this subsection focuses on ARARs containing specific minimum numerical standards.

Washington State has enacted environmental laws and promulgated regulations to implement or co-implement several major federal laws through federally approved programs, such as the CWA, Clean Air Act, and RCRA. Washington's state cleanup law, MTCA, is an ARAR for the EW OU, and sediment sites under MTCA are regulated by SMS, which promulgates methods for developing and complying with cleanup levels. The PRGs are developed in Sections 4.3 and 4.4 to comply with SMS.

Table 4-1
ARARs for the East Waterway[a]

Topic	Threshold	Regulatory Citation: Federal	Regulatory Citation: State	Comment
Soil, Groundwater, Surface Water and Air Quality	Cleanup standards for multiple media	–	Model Toxics Control Act (MTCA) (Chap. 70.105D RCW; WAC 173-340)	MTCA established excess cancer risk standards, among other important standards.
Sediment Quality	Sediment cleanup standards	–	Sediment Management Standards (SMS) (WAC 173-204)	The SMS are promulgated rules under MTCA for excess human health cancer risk standards, non-cancer risk standards for human health and higher trophic level species, and numerical criteria for the protection of benthic community.
Surface Water Quality	Surface water quality standards	National Recommended Ambient Water Quality Criteria established under Section 304(a) of the Clean Water Act (33 USC 1251 et seq), water.epa.gov/scitech/swguidance/standards/criteria/index.cfm	Surface Water Quality Standards (RCW 90.48; WAC 173-201A) State Aquatic Life Criteria (National Toxics Rule 40 CFR 131.36(b)(1) as applied to Washington per 40 CFR 131.36(d)(14) State Human Health Criteria)	National Recommended Federal Water Quality Criteria established under Section 304(a) of the Clean Water Act are relevant and appropriate. More stringent State surface water quality standards apply where the State has adopted, and EPA has approved, Water Quality Standards. Both chronic and acute standards are used.
Land Disposal of Waste	Disposal of materials containing polychlorinated biphenyls	Toxic Substances Control Act (TSCA) (15 USC 2605; 40 CFR Part 761)	–	None found to date that exceed TSCA levels
	Hazardous waste	Resource Conservation and Recovery Act (RCRA) Land Disposal Restrictions (42 USC 6901-92k)	Dangerous Waste Regulations Land Disposal Restrictions (RCW 70.105; WAC 173-303, -140, -141)	None found to date that exceed RCRA levels
Waste Treatment Storage and Disposal	Disposal limitations	RCRA (42 USC 6901-6992k; 40 CFR 260-279)	Dangerous Waste Regulations (RCW 70.105; WAC 173-303)	–
Noise	Maximum noise levels	–	Noise Control Act of 1974 (RCW 70.107; WAC 173-60)	–
Groundwater	Groundwater quality	Safe Drinking Water Act Maximum Contaminant Levels and non-zero Maximum Contaminant Level Goals (40 CFR 141)	RCW 43.20A.165 and WAC 173-290-310	For on-site potable water, if any.
Dredge/Fill and Other In-water Construction Work	Discharge of dredged/fill material into navigable waters or wetlands	Clean Water Act (Sections 401, 404; 33 USC 1341-1344; 40 CFR 121.2, 230, 231; 33 CFR 320, 322-3, 328-30); Rivers and Harbors Act (33 USC 401 et seq)	Hydraulic Code Rules (RCW 75.55; WAC 220-110)	For in-water dredging, filling, or other construction.
	Open-water disposal of dredged sediments	Marine Protection, Research and Sanctuaries Act (33 USC 1401-1445; 40 CFR 227)	Dredged Material Management Program (RCW 79.105.500; WAC 332-30-166 (3))	–
Solid Waste Disposal	Requirements for solid waste handling, management, and disposal	Solid Waste Disposal Act (42 USC 6901-92k; 40 CFR 257, -258)	Solid Waste Handling Standards (RCW 70.95; WAC 173-350)	–
Discharge to Surface Water	Point source standards for new discharges to surface water	National Pollutant Discharge Elimination System (40 CFR 122, 125)	Discharge Permit Program (RCW 90.48; WAC 173-216, -222)	–
Shoreline	Construction and development	–	Shoreline Management Act (RCW 90.58; WAC 173-16)	For construction within 200 feet of the shoreline.
Floodplain Protection	Avoid adverse impacts, minimize potential harm	Executive Order 11988, Protection of flood plains (40 CFR 6, Appendix A); Federal Emergency Management Agency National Flood Insurance Program Regulations (44 CFR 60.3(d)(3))	Growth Management Act critical areas	For in-water construction activities, including any dredge or fill operations. Includes local ordinances: KCC Title 9 and SMC 25.09.
Critical (or Sensitive) Area	Evaluate and mitigate impacts	–	Growth Management Act (RCW 36.70A)	–

Table 4-1
ARARs for the East Waterway[a]

Topic	Threshold	Regulatory Citation: Federal	Regulatory Citation: State	Comment
Habitat for Fish, Plants, or Birds	Evaluate and mitigate habitat impacts	Clean Water Act (Section 404 (b)(1)); 1981 U.S. Fish and Wildlife Mitigation Policy (44 CFR 7644-7663)[b]; U.S. Fish and Wildlife Coordination Act (16 USC 661 et seq); Migratory Bird Treaty Act (16 USC 703-712)	–	–
Pretreatment Standards	National pretreatment standards	–	40 CFR Part 403; Metro District Wastewater Discharge Ordinance (KCC) to be considered (as a local requirement)	–
Native American Graves and Sacred Sites	Evaluate and mitigate impacts to cultural resources	Native American Graves Protection and Repatriation Act (25 USC 3001 et seq.; 43 CFR Part 10) and American Indian Religious Freedom Act (42 USC 1996 et seq.)	–	–
Critical Habitat for Endangered Species	Conserve endangered or threatened species, consult with species listing agencies	Endangered Species Act of 1973 (16 USC 1531 et seq; 50 CFR 200, -402); Magnuson-Stevens Fishery Conservation and Management Act (16 USC 1801-1884)	Endangered, threatened, and sensitive wildlife species classification (WAC 232-12-297)	Consult and obtain Biological Opinions.
Historic Sites or Structures	Requirement to avoid, minimize, or mitigate impacts to historic sites or structures	National Historic Preservation Act (16 USC 470f; 36 CFR Parts 60, 63, and 800)	–	Considered if implementation of the selected remedy involves removal of historic sites or structures.

Notes:
a. The East Waterway is being remediated under CERCLA and will comply with CERCLA requirements and guidance. ARARs are requirements other than CERCLA.
b. To-Be-Considered criterion does not qualify as an ARAR.

ARAR – Applicable or relevant and appropriate requirement
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
CFR – Code of Federal Regulations
EPA – U.S. Environmental Protection Agency
KCC – King County Code
RCW – Revised Code of Washington
SMC – Seattle Municipal Code
USC – United States Code
WAC – Washington Administrative Code

Recommended federal WQC developed to protect ecological receptors and human consumers of fish and shellfish are relevant and appropriate requirements pursuant to CERCLA Section 121 (d)(2)(A)(ii) and RCW 70.105D.030(2)(e). Although ambient water quality criteria for organisms only are an ARAR for the EW, ambient water quality criteria for consumption of organisms and water are not relevant because the EW is not a source of drinking water. Under CERCLA, state water quality standards (WQS) approved by EPA are generally applicable requirements under the CWA. National recommended federal WQC established pursuant to Section 304(a)(1) of the CWA are compiled and presented on the EPA website at http://www.epa.gov/waterscience/criteria/wqctable/. Although these criteria are advisory for CWA purposes (to assist states in developing their standards), the last sentence of CERCLA Section 121(d)(2)(A)(ii) makes them generally relevant and appropriate requirements for CERCLA site remedial actions.

Consequently, the more stringent of the recommended federal marine WQC and the state marine WQS are ARARs for the site. Washington State WQS for the protection of aquatic life found at WAC 173-201A-240 meet the federal requirements of Section 303(c)(2)(B) of the CWA and are at least as stringent as the recommended federal WQC. Furthermore, in Washington State, an antidegradation policy helps prevent unnecessary lowering of water quality (WAC 173-201A-300 through WAC 173-201A-410). It is also recognized that portions of many waterbodies cannot meet the assigned criteria due to the natural conditions of the waterbody. Per WAC 173-201A-260, when a waterbody does not meet its assigned criteria due to human structural changes that cannot be effectively remedied (as determined consistent with the federal regulations at 40 CFR 131.10), then alternative estimates of the attainable water quality conditions, plus any further allowances for human effects specified in this section for when natural conditions exceed the criteria, may be used to establish an alternative criteria for the waterbody (see WAC 173-201A-430 and 173-201A-440).[33] Therefore, toxic, radioactive, or deleterious material concentrations must be below those which have the potential, either singularly or cumulatively, to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health (see WAC 173-201A-240, toxic substances, and 173-201A-250, radioactive substances).

[33] Alternative criteria have not been developed for the EW at this time.

4.2 Development of Remedial Action Objectives

The RAOs are narrative statements that describe specific goals for protecting human health and the environment. RAOs describe in general terms what the cleanup will accomplish for the EW. RAOs help focus the development and evaluation of remedial alternatives and form the basis for establishing PRGs. EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988) specifies that RAOs are to be developed based on the results of the HHRA and ERA. Other EPA guidance (EPA 1991b, 1999a) states that RAOs should specify the following:

- The exposure pathways, receptors, and COCs
- An acceptable concentration or range of concentrations for each exposure pathway

Section 2 summarized the SRI, including the chemical and physical CSM. Section 3 summarized the results of the risk assessments, which identified receptors, exposure pathways, risk driver COCs, and, where calculable, RBTCs. The RAOs presented here were crafted based on the SRI and findings from the baseline ERA (Windward 2012a) and HHRA (Windward 2012b).

4.2.1 Remedial Action Objectives for the East Waterway Operable Unit

The results of the baseline HHRA and ERA indicate that remedial action is warranted to reduce unacceptable human health and ecological risks posed by COCs in the EW OU. Unacceptable risks were estimated for certain human health exposure scenarios (through seafood consumption and direct contact exposure pathways) and for certain ecological risks (for benthic organisms and for other ecological receptors).

For human health, EPA defines a generally acceptable risk range for excess cancer risks as between 1 in 10,000 (1×10^{-4}) and 1 in 1 million (1×10^{-6}) (i.e., the "target risk range"), and for non-cancer risks, an HI[34] of 1 or less is considered acceptable (EPA 1991b). Excess cancer risks greater than 10^{-4} or HIs greater than 1 generally warrant a response action (EPA 1997b).

[34] HIs are calculated as the sum of hazard quotients with similar non-cancer toxic endpoints. HIs include both background and site-specific exposures, so achieving an HI of less than 1 may not be possible in some cases.

Appendix A details how cleanup levels are established under SMS. The SMS consider individual excess cancer risk RBTCs (one COC at a time) of no greater than 1×10^{-5} to achieve the CSL and 1×10^{-6} to achieve the SCO, and total excess cancer risks (all carcinogens combined) of no greater than 1×10^{-5} (to achieve both the SCO and CSL). For non-cancer risks, SMS consider RBTCs based on an HQ of 1 for individual contaminants and an HI of 1 for multiple contaminants with similar types of toxic action (to achieve both the SCO and the CSL).

Both CERCLA and SMS also consider background concentrations and PQLs when developing cleanup levels, as discussed in Sections 4.3 and 4.4.

Based on guidance provided under CERCLA and other requirements provided in MTCA/SMS, four RAOs have been identified for the cleanup of EW sediments. These RAOs, which are preliminary and will be finalized in the ROD, are identified below, and a discussion of each RAO follows.

RAO 1: Reduce risks associated with the consumption of contaminated resident EW fish and shellfish by adults and children with the highest potential exposure to protect human health.

Lifetime excess cancer risks from human consumption of resident EW seafood are estimated to be greater than 1×10^{-5} for some individual carcinogens, and greater than 1×10^{-4} for carcinogens cumulatively under RME seafood consumption scenarios. In addition, the estimated non-cancer risks exceed an HI of 1 (see Table 3-4b). These estimated risks warrant response actions to reduce exposure.

Total PCBs, cPAHs, and dioxins/furans are the primary risk driver COCs that contribute to the estimated risks based on consumption of resident seafood. Achieving RAO 1 requires that site-wide average[35] concentrations of COCs in sediment or bioavailability be reduced, which, in conjunction with source control, is expected to reduce COC concentrations in water and

[35] The FS uses average concentrations to evaluate the effectiveness of alternatives in attaining RAOs. In practice, compliance with cleanup levels will be based on the 95% upper confidence limit on the mean (UCL95).

fish and shellfish tissue. Surface water will not be directly remediated in the EW OU but will be improved by implementation of the selected remedy and by source control.

Exposure of fish and shellfish to COCs in sediment occurs within the biologically active zone. As reported in the SRI (Windward and Anchor QEA 2014), this zone is estimated to be the upper 10 cm of sediment so that is the point of compliance for this RAO. Deeper, undisturbed sediments contribute negligibly to the risks addressed by this RAO if contaminants in these deeper sediments do not migrate into or are exposed to the biologically active zone. However, as discussed in Section 2.11, shallow subsurface contamination may be incorporated into the biologically active zone due to vessel scour[36] in some areas and, therefore, may need to be addressed to achieve this RAO. RAO 1 refers to resident fish and shellfish, which spend an extensive amount of time in the EW and tend to accumulate certain hazardous substances. However, anadromous fish are not included because they spend most of their lives outside the EW and do not accumulate significant amounts of hazardous substances from the EW.

With regard to seafood consumption, bioaccumulative COCs enter the food web from both sediment and water. For example, the food web model used to predict tissue PCB concentrations (refer to Appendix C of the SRI; Windward and Anchor QEA 2014) assumes that the exposure of fish and shellfish to PCBs occurs through their exposure to both sediments and surface water.

The objective of sediment remediation is to reduce risk from seafood consumption to meet the regulatory thresholds established (in this case, 1×10^{-6} for individual carcinogens, 1×10^{-5} for multiple carcinogens, and non-cancer risks of HI of 1; or to background or PQL concentrations). Sediment remediation will target background concentrations or PQLs if sediment concentrations related to risk thresholds noted above are below those levels (Section 4.3.3).

[36] Erosion from possible slumping/sloughing of slopes, erosion and mixing due to bioturbation and tidal flow, and erosion from potential seismic activity are minimal in comparison to vessel impacts in the EW.

Substantial reductions in the concentrations of such COCs in sediment achieved through remediation should also reduce the concentrations of those COCs in surface water, thereby contributing to reducing their concentrations in fish and shellfish tissue and ultimately reducing human health risks. The relationships between sediment, surface water, and tissue concentrations are complex, and will be assessed through long-term monitoring of the remedial actions. Institutional controls, such as seafood consumption advisories, public outreach, and education are anticipated to be necessary, depending on the human health risks following remediation.

RAO 2: Reduce risks from direct contact (skin contact and incidental ingestion) to contaminated sediments during netfishing and clamming to protect human health.

Lifetime excess cancer risks from human direct contact (which includes incidental sediment ingestion and dermal contact with sediment) RME scenarios (netfishing and tribal clamming) are estimated to be within EPA's 10^{-4} to 10^{-6} target risk range (Table 3-6) for the individual risk driver COCs. Some individual excess cancer risks exceed 1×10^{-5}, and total risks from all risk driver COCs exceed 1×10^{-5}, both of which are SMS thresholds. Therefore, the risks associated with these exposure pathways warrant response actions to reduce exposure.

Arsenic was identified as a risk driver based on its excess cancer risk (above the applicable thresholds), contribution to the overall excess cancer risk (these COCs contributed the majority of the risk), and high detection frequency (greater than 80%). No HIs were greater than 1 for any of the direct contact RME scenarios, and thus there are no COCs or risk drivers for non-cancer risks based on direct contact.

Achieving RAO 2 requires that average concentrations of COCs be reduced at locations and depths within the sediment where people have the potential to be exposed. For netfishing activities, exposure is over the entire EW and to surface sediments (0 to 10 cm). Direct contact risks in the clamming areas are assumed to result from exposure to the upper 25 cm[37]

[37] The use of the 25-cm depth in the intertidal areas was based on site-specific clam burrowing depths for clam species collected in the EW (less than 30 cm for butter clams, less than 10 cm for littleneck clams, and approximately 10 cm for cockles), consistent with Pacific Northwest-specific information (Kozloff 1973). The

depth interval, which accounts for potential exposures to clammers, who may dig holes deeper than 10 cm. Deeper sediments in other areas do not contribute appreciably to these risks unless they could be exposed by future disturbances (e.g., erosion, propeller scour, earthquakes). However, as discussed in Section 2.11, shallow subsurface contamination may be incorporated into the biologically active zone primarily due to vessel scour[38] in some areas (Figure 2-15) and, therefore, may need to be addressed to achieve this RAO.

The objective of sediment remediation is to reduce risk from direct contact to meet the regulatory risk thresholds established (in this case, 1×10^{-6} for individual carcinogens, 1×10^{-5} for multiple carcinogens; or to background concentrations). Sediment remediation will target background concentrations if sediment concentrations related to risk thresholds are below background concentrations (Section 4.3.3). Institutional controls, such as public outreach and education, may be necessary to further reduce risk, depending on the potential human health risks following remediation.

RAO 3: Reduce to protective levels risks to benthic invertebrates from exposure to contaminated sediments.

The SMS provide both chemical and biological effects-based criteria for benthic invertebrates. The numerical SMS chemical criteria are available for 47 contaminants or groups of contaminants (i.e., SQS and CSL). These numerical chemical criteria are based on AETs developed for four different benthic endpoints by the Puget Sound Estuary Program (Barrick et al. 1988). An AET is the concentration of a specific contaminant above which a significant adverse biological effect was always found among the several hundred samples used in its derivation. In general, the lowest of the four AETs for each contaminant was identified as the SQS; the second lowest AET was identified as the CSL. According to the SMS, locations with all contaminant concentrations less than or equal to the SQS are defined as having no acute or chronic adverse effects on biological resources, locations with any contaminant concentrations between the SQS and the CSL are defined as having the

25-cm depth provides a good estimate of the average depth to which individuals might dig to collect intertidal clams.

[38] Erosion from potential slumping/sloughing of slopes, erosion and mixing due to bioturbation and tidal flow, and erosion from potential seismic activity are minimal in comparison to vessel impacts in the EW.

potential for minor adverse effects, and locations with any contaminant concentration greater than the CSL are defined as having a likelihood of having minor adverse effects (refer to Section 5 of the SRI; Windward and Anchor QEA 2014).

The baseline ERA (Windward 2012a) reported that 29 contaminants were detected in surface sediment at one or more locations within the EW at concentrations exceeding their respective SQS (see Table 3-1). Thus, the ERA determined that these 29 contaminants are COCs because they pose a risk to the benthic invertebrate community. These 29 COCs are designated as risk drivers for this pathway. In addition, the ERA identified TBT as a COC for benthic invertebrates because of LOAEL-based HQs greater than 1, and TBT is also designated as a risk driver for the benthic invertebrate community.

Benthic organisms reside primarily in the biologically active zone (uppermost 10 cm) of intertidal and subtidal sediments of the EW OU (Section 2 of the SRI; Windward and Anchor QEA 2014). Deeper sediments in areas subject to disturbance (e.g., from erosion, propeller scour, and earthquakes) that contain COCs at concentrations above the SQS may warrant response actions to maintain compliance in the biologically active zone.

RAO 4: Reduce to protective levels risks to crabs and fish from exposure to contaminated sediment, surface water, and prey.

Total PCBs were identified as a risk driver COC for English sole and brown rockfish because PCBs in fish tissue exceeded the two LOAEL TRVs that were associated with adverse effects (Section 3.1.3). Three COCs were identified for crab but not determined to be risk driver COCs (see Table 3-2). No adverse effects are expected for birds or mammals because no contaminants of potential concern have concentrations exceeding the relevant threshold concentrations, and thus there are no COCs for these receptors. Thus, achievement of RAO 4 is based on addressing PCB risk to fish.

Fish are indirectly exposed to PCBs in sediment primarily through the consumption of prey. Therefore, reductions in site-wide average concentrations of PCBs in sediment through remedial action should reduce PCB concentrations in fish. The potential for exposure of prey to COCs occurs primarily within the biologically active zone (upper 10 cm of sediment).

Deeper sediments, if left undisturbed, contribute negligibly to the risks addressed by this RAO. Deeper sediments in areas subject to disturbance (e.g., from erosion, propeller scour, and earthquakes) that contain COCs at concentrations above an action level designed to achieve the RAO 4 PRGs may warrant response actions to maintain compliance in the biologically active zone.

Expected improvements to surface water quality will be achieved through remediation of site sediments; no active remediation of surface water is anticipated. Remediation will reduce COC concentrations in the EW OU sediments; this in turn should also reduce those same COC concentrations in surface water, thereby contributing to a reduction of their concentrations in fish tissue (including prey species). The relationships between sediment, surface water, and tissue concentrations are complex, and will be assessed through long-term monitoring following completion of the remedial actions.

4.2.2 Role of Source Control

Active sediment remediation of COCs that have previously accumulated in sediments over time will initially address a major portion of the risks addressed in each RAO. However, the presence of ongoing contaminant source inputs will affect the long-term equilibrium concentrations that can be expected to be achieved over time within the EW OU sediments. Source control activities that are ongoing or that will occur in the future will reduce lateral source inputs to the EW and tend to lower these long-term equilibrium concentrations and reduce the extent of recontamination that will occur in sediments. The recontamination predictions included in the FS provide a basis for understanding how the ongoing source inputs may impact the remedial decision for the EW. The recontamination predictions in Section 4 of Appendix J indicate that an analysis of source control alternatives is not needed in this FS, and that specific source control remedial actions will not be specified in the Proposed Plan or ROD.

The SRI included characterization of each of the different pathways by which ongoing contaminant sources could potentially recontaminate EW sediments, as described in the FS in Section 2.11.3. This FS includes recontamination predictions that evaluate the potential impact of ongoing direct discharges and the transport of upstream inputs on EW sediment quality.

As described in Section 2.12, multiple existing source control programs are currently operating within the EW OU and its watersheds. These programs include the work of the Port, City, and County, as well as the work of multiple regulatory agencies (e.g., Ecology, PSCAA, and EPA). Collectively, this source control work includes actions being taken under multiple programs and regulatory authorities.

Ongoing source control activities will assist in completing the following:

- Reduce the potential for contaminants in sediments to exceed the EW RALs to be established in the ROD with a long-term goal of achieving the site PRGs.
- Achieve adequate source control to allow sediment cleanup to be implemented.
- Support long-term suitability and success of current and future habitat restoration opportunities.

Source control is an ongoing, iterative process that continually produces new information and actions.

4.3 Process for Development of Preliminary Remediation Goals

PRGs are the COC endpoint concentrations associated with each RAO that are believed to be sufficient to protect human health and the environment based on available site information (EPA 1997b). The PRGs are used in the FS to guide evaluation of proposed remedial alternatives, but they are not the final CERCLA cleanup levels. EPA will ultimately select those levels in the ROD. This section summarizes the process for development of PRGs, which will be used by EPA to determine sediment cleanup levels and performance standards for the EW OU.

PRGs are developed for each risk driver COC, and are expressed as sediment concentrations that are intended to achieve the corresponding RAO. PRGs are based on consideration of the following factors:

- ARARs, including SMS cleanup level development requirements
- RBTCs based on the human health and ecological risk assessments
- Background concentrations if protective RBTCs are below background concentrations
- Analytical PQLs if protective RBTCs are below concentrations that can be quantified by chemical analysis

This section presents the numerical criteria in these categories to enable a comprehensive analysis and identification of PRGs. The pertinent information is then compiled and numerical PRGs are identified for each risk driver COC and each RAO.

4.3.1 Role of ARARs

Under CERCLA, ARARs are any standard, requirement, criteria, or limitation under federal environmental law or more stringent promulgated standard, requirement, criteria or limitation under State environmental or facility siting law that is legally "applicable" to the hazardous substance (or pollutant or contaminant) concerned or is "relevant and appropriate" under the circumstances of the release. Important federal and state ARARs for development of EW cleanup levels include federal AWQC and the Washington State SMS, MTCA, and water quality standards.

The SMS established requirements for remediation of contaminated sediments. PRGs are developed to protect human health, the benthic community, and higher trophic level species. PRGs developed for RAOs 1 and 2 are consistent with the SMS for protection of human health, PRGs developed for RAO 3 are consistent with the SMS for protection of the benthic community, and PRGs developed for RAO 4 are consistent with the SMS for protection of higher trophic level species. Appendix A discusses the SMS ARAR in greater detail.

Under the SMS, sediment cleanup levels (SCLs) may be established on a site-specific basis within an allowable range of contaminant concentrations. The low end of the range is the SCO, and the high end of the range is the cleanup screening level (CSL). The SCL is originally set at the SCO; however, it may be adjusted upward from the SCO based on consideration of whether it is technically possible to achieve the SCO at the applicable point of compliance[39] and whether meeting the SCO will have a net adverse environmental effect on the aquatic environment, natural resources, and habitat. The SCL may not be adjusted upward above the CSL (WAC 173-204-560).

The SCO is the higher of the risk-based levels, PQLs, and natural background. The CSL is the higher of the risk-based levels, PQLs, and regional background. For RAOs 1 and 2, the SCO (lower) risk-based values are based on an estimated lifetime excess risk of less than or equal to 1×10^{-6} for individual carcinogens, less than or equal to 1×10^{-5} for multiple carcinogens or exposure pathways, or HQ less than or equal to 1 for individual contaminants and HI of less than or equal to 1 for multiple contaminants with similar toxic actions. The CSL (higher) risk-based values are based on an estimated lifetime excess risk of less than or equal to 1×10^{-5} for individual carcinogens, and the same as the SCO for multiple carcinogens or exposure pathways, and non-carcinogens.

At the SCO level, natural background values may be used when they are higher than risk-based levels or PQLs. Natural background values have been established for some contaminants in the Puget Sound area.[40] At the CSL level, regional background values may be used when they are higher than risk-based levels or PQLs. Regional background values have not been established for the geographic area that would include EW. Therefore, PRGs based on regional background concentrations are not considered in this FS.

For RAO 3, the SMS contain numerical sediment contaminant concentration criteria for the protection of the benthic community. The SCO (lower) values are concentrations that

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[39] The SMS define "technically possible" as "capable of being designed, constructed and implemented in a reliable and effective manner, regardless of cost." WAC 173-204-505(23). Ecology guidance, provided in SCUM II (Ecology 2017), confirms that this definition includes both the ability to attain, and to reliably and effectively maintain, the natural background cleanup level by stating that upward adjustment of the cleanup level should be based on "whether it is technically possible to achieve and maintain the cleanup level at the applicable point of compliance." [SCUM II 7.2.3.1, page 7-4].

[40] Ecology's methods for determining natural background concentrations were established in agency guidance, but EPA does not consider agency guidance to be an ARAR (Ecology 2017). EPA disagrees with the statistical method used by Ecology to determine natural background concentrations. Use of EPA's preferred statistical method results in lower values for natural background than those produced using Ecology's method. Natural background values determined using EPA's statistical method are used in this FS.

Ecology has determined will have no adverse effects on the benthic community. The CSL (higher) values represent concentrations that Ecology has determined will have minor adverse effects. The SCO for protection of the benthic community (WAC 173-204-562) is referred to as the "SQS" in this document for consistency with previous documents, and these values are equivalent to the marine SQS (WAC 173-204-320). The SQS are applied on a point basis to the biologically active zone of the sediments (i.e., upper 10 cm). Co-located sediment toxicity test results override the numerical criteria for determining compliance with RAO 3. The SCLs for RAO 3 are applied on a point-by-point basis (i.e., without area averaging).

Based on preliminary evaluations, the EW OU cleanup is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2), protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. Modeling, in Appendix A, of the hypothetical maximum remediation scenario at the completion of cleanup implementation and modeling of long-term site-wide concentrations following source control of LDW and EW lateral inputs both predict that surface sediments in the EW OU will not attain all natural background-based PRGs for protection of human health for seafood consumption (RAO 1). Long-term site-wide concentrations are driven primarily by the ongoing contribution of elevated concentrations from diffuse, nonpoint sources of contamination that contribute to regional background concentrations.[41] However, achieving the MTCA/SMS ARARs may nonetheless occur in one of the following two ways:

- Post-remedy monitoring may demonstrate sediment concentrations lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for a Sediment Recovery Zone (SRZ), as provided by the SMS at WAC 173-204-590(3) (see Section 5 of Appendix A).

[41] Source control and sediment cleanup measures are assumed for FS modeling purposes to effectively address discrete sources of contamination, leaving sediment concentrations that are assumed to be "primarily attributable to diffuse sources, such as atmospheric deposition or storm water, not attributable to a specific source or release." WAC 173-204-505(16).

- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or Explanation of Significant Differences (ESD) (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition to these two potential MTCA/SMS ARARs compliance mechanisms, a final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs such that a technical impracticability (TI) waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

Because it is not known whether, or to what extent, the SMS ARARs for total PCBs and dioxins/furans will be achieved in the long term, the selection of which of the two compliance mechanisms described above (either meeting the natural background PRG in a reasonable restoration timeframe, or upwardly adjusting the SCL to regional background and meeting it in a reasonable restoration timeframe) is not identified at this time.

As described in Section 4.1, surface water quality criteria are ARARs for the EW. The water column is affected by the sediment contaminant concentrations, as well as by other factors, including ongoing releases, inflowing water from the Green/Duwamish River system and Elliott Bay, direct discharges to the EW, and atmospheric deposition. The water column cannot practicably be directly remediated, but will be improved by implementation of the selected remedy and by source control actions as discussed in Section 4.2.2. Surface water is a key exposure pathway for consumption of aquatic organisms by humans and wildlife. Following construction, surface water quality data will be compared to these ARAR values to measure progress toward achieving RAOs 1 and 4, and will be evaluated as discussed in Section 4.2.1. Because the WQC are CERCLA ARARs, the quality of EW surface water will have to meet the more stringent of the recommended federal WQC and state WQS for aquatic life and human health (for consumption of organisms only) or be waived at or before completion of CERCLA remedial action.

Water quality improvements are anticipated as a result of sediment remediation and source control. Water quality monitoring will be part of the selected remedy to help measure the efficacy of sediment remediation and source control, and to assess compliance with ARARs. Based on upstream and downstream water quality measurements, none of the remedial alternatives developed and evaluated in this FS are anticipated to meet all surface water quality standards. A surface water quality ARAR waiver could be issued by EPA; potential ARAR waivers are listed in Section 121(d)(4) of CERCLA. The most common waiver is for TI.

4.3.2 Role of RBTCs

The SRI developed site-specific sediment RBTCs (summarized in Section 3.3 of this document) for each of the risk driver COCs. RBTCs for human health were calculated based on risks associated with the direct sediment contact RME scenarios and seafood consumption RME scenarios. RBTCs for fish were calculated based on prey consumption using a calibrated FWM (applicable only to PCBs). For the benthic invertebrate community, RBTCs were set at the SQS and CSL for SMS parameters and were based on site-specific BSAF values for TBT.

Total PCBs, cPAHs, and dioxins/furans are the risk driver COCs for the human seafood consumption pathway. Sediment RBTCs for total PCBs were calculated for the 1×10^{-4} excess cancer risk level and are applied as site-wide average concentrations.[42, 43] As discussed in Section 3.3.4, sediment RBTCs based on the seafood consumption pathway were not calculated for cPAHs because correlations between sediment contaminant concentrations and clam receptor tissue concentrations could not be established.[44] Sediment RBTCs for

[42] Compliance for remedial actions for RAOs 1, 2, and 4 will be based on site-wide or clamming area UCL95 of post-remediation sediment sampling data.

[43] For the excess cancer risk levels of 1 in 1,000,000 (1×10^{-6}) and 1 in 100,000 (1×10^{-5}) and for the non-cancer HQ of 1, even at a total PCB concentration of 0 µg/kg dw in sediment, the food web model predicted total PCB concentrations in tissue that would result in a risk estimate greater than the risk levels for the RME seafood consumption scenarios because of the contribution of total PCBs from water alone, even at concentrations similar to those in upstream Green River water (i.e., 0.3 ng/L). Therefore, sediment RBTCs for these risk levels were represented as "< 1" (see Table 3-13).

[44] Data show little relationship between clams and sediment for cPAHs, and clam concentrations may be more related to the surface water pathway.

dioxins/furans were calculated for the 1 x 10^{-4}, 1 x 10^{-5}, and 1 x 10^{-6} excess cancer risk level and for an HQ of 1 and are applied as site-wide average concentrations.

Arsenic was identified as human health risk driver COCs for the direct sediment contact pathway. Sediment RBTCs for this hazardous substance was presented in Table 3-10 for the two direct sediment contact RME scenarios (i.e., netfishing on a site-wide basis and tribal clamming in clamming areas). These sediment RBTCs are average concentrations applied to the spatial area over which exposure would reasonably be expected.

A range of total PCB sediment RBTCs was calculated to protect fish depending on the tissue RBTC (based on toxicity reference values and associated uncertainties) and species. These RBTCs are applied as site-wide average concentrations. Appendix A describes the method used to establish a sediment PRG for each of two fish species.

4.3.3 Role of Background Concentrations

Both CERCLA and the SMS (MTCA) consider background hazardous substance concentrations when formulating PRGs and cleanup levels. Both recognize that setting numerical cleanup goals at levels below background is impractical (because of the certainty of recontamination to at least the background concentration). The SMS define natural background as the concentrations of hazardous substances that are consistently present in an environment that have not been influenced by localized human activities. Thus, under the SMS, a natural background concentration can be defined for man-made compounds even though they may not occur naturally (e.g., PCBs deposited by atmospheric deposition into an alpine lake). According to CERCLA guidance, natural background refers to substances that are naturally present in the environment in forms that have not been influenced by human activity (e.g., naturally occurring metals).

SMS cleanup levels cannot be set at concentrations below natural background (WAC 173-204-560). Similarly, CERCLA guidance states that natural background concentrations establish a limit below which a lower cleanup level cannot be achieved (EPA 2005).

Both cleanup programs also recognize that natural and man-made hazardous substance concentrations can occur at a site in excess of natural background concentrations, not as a result of controllable local site-related releases but caused by human activities in areas removed from the site and natural processes that transport the contaminants to the site (e.g., atmospheric uptake, transport, and deposition). CERCLA defines "anthropogenic background" as natural and human-made substances present in the environment as a result of human activities, but not related to a specific release from the CERCLA site undergoing investigation and cleanup (EPA 2002b). The SMS define the term "regional background" as concentrations in an Ecology-defined geographic area that are attributable to "diffuse sources, such as atmospheric deposition or storm water, not attributable to a specific source or release" (WAC 173-204-505 (16)). CERCLA generally does not require cleanup to concentrations below anthropogenic background concentrations; the SMS allow upward adjustment of cleanup levels to regional background. More stringent state standards must be met by a CERCLA remedial action or waived by EPA at or before completion of the remedial action. The adjustment of cleanup standards for total PCBs and dioxins/furans from natural background to regional background is discussed in Appendix A.

4.3.3.1 Natural Background in Sediment

This section presents estimates of natural background concentrations for total PCBs, cPAHs, arsenic, and dioxins/furans in sediment.[45] To characterize natural background, marine sediment data were compiled from areas within Puget Sound that have not been influenced by localized human activities. These data represent non-urban, non-localized concentrations that exist as a result of natural processes and/or the large-scale distribution of these hazardous substances from anthropogenic sources in a large marine receiving body.

The DMMP (comprised of USACE, EPA, Ecology, and DNR) collected sediment data throughout Puget Sound and the Strait of Juan de Fuca in the summer of 2008 and documented the results in a report called *Final Data Report: OSV Bold Summer 2008 Survey* (DMMP 2009). Data were collected from 70 sampling locations throughout Puget Sound, as well as from the area around the San Juan Islands and the Strait of Juan de Fuca. Locations for each target sampling station are displayed in Figure 4-1. A subset of these sample locations

[45] EPA will set cleanup levels and remediation goals in the ROD.

(N = 20) consisted of locations in four reference areas (Carr Inlet, Samish Bay, Holmes Harbor, and Dabob Bay) established by Ecology. In each of these reference areas, five target sediment sampling locations were located based on a stratified random sampling design. The remaining 50 sample locations were spread throughout Puget Sound and the straits of Georgia and Juan de Fuca and were intended to represent areas outside the influence of urban bays and known point sources. At five stations, a duplicate sample (or field split) was collected for quality assurance purposes. Samples were analyzed for the full suite of DMMP contaminants, including SVOCs, dioxins/furans, PCB Aroclors, PCB congeners, organochlorine pesticides, and trace metals, as well as for sediment conventionals (e.g., TOC, grain size, percent solids).

The statistical methods used to develop background concentrations are important for consistency with other regional sites and for measuring compliance. EPA calculates natural background concentrations based on the UCL95 from the background population, as was also presented in the LDW FS (AECOM 2012). Ecology uses an alternate method for determining natural background concentrations[46] which was established in Ecology's Sediment Cleanup User's Manual (SCUM) II (Ecology 2017). SCUM II is not an ARAR under CERCLA, although portions of SCUM II may be evaluated as "to be considered" criteria. EPA disagrees with the statistical method used by Ecology to determine natural background concentrations for establishing PRGs in compliance with CERCLA. Use of EPA's preferred statistical method results in lower values for natural background than those produced using Ecology's method. Natural background values determined using EPA's statistical method are used in this FS. Summary statistics for natural background calculations are presented in Table 4-2 for each of the four human health risk driver COCs.

Natural Background for Arsenic in Sediment

Arsenic was detected in all of the samples from the OSV *Bold* Survey (Table 4-2). Concentrations ranged from 1.1 to 21 mg/kg dw, with a mean concentration of 6.5 mg/kg dw, a 90th percentile of 11 mg/kg dw. Calculating the UCL95 of the OSV *Bold* Survey dataset results in a natural background value of 7 mg/kg dw.

[46] For informational and comparison purposes, Appendix A presents the natural background values calculated by Ecology in SCUM II.

Natural Background for Total PCBs in Sediment

Total PCBs as Aroclors were below reporting limits in the majority of sediment samples from the OSV *Bold* Survey (Table 4-2). The PCB congener method, with its lower reporting limits, produced a detection frequency of 100%, based on quantifying at least one PCB congener in each sample. Total PCBs in each sample were calculated by summing the concentrations of all detected PCB congeners, consistent with the protocol in the SMS for reporting total PCBs by summing the concentrations of all detected PCB Aroclors. Using the congener results, total PCB concentrations ranged from 0.01 to 10.6 µg/kg dw, with a mean of 1.2 µg/kg dw a 90th percentile of 2.7 µg/kg dw. Calculating the UCL95 of the OSV *Bold* Survey dataset results in a natural background value of 2 µg/kg dw.

Table 4-2

Summary of Arsenic, Total PCB, cPAH, and Dioxin/Furan Sediment Data for Natural Background Concentrations

Human Health Risk Driver COC	Detection Frequency	Minimum	Maximum	Mean	Median	90th Percentile	EPA-calculated UCL95 (rounded value)[b]
Arsenic (mg/kg dw)	70/70	1.1	21	6.5	6.0	11	7
Total PCBs as Congeners (µg/kg dw)[a]	70/70	0.01	10.6	1.2	0.7	2.7	2
cPAHs (µg TEQ/kg dw)	61/70	1.3	57.7	7.1	4.5	15	9
Dioxins/furans (ng TEQ/kg dw)	70/70	0.23	11.6	1.4	1.0	2.2	2

Notes:
1. The summary statistics above are for the dataset collected throughout Puget Sound by DMMP in 2008 and referred to as the OSV *Bold* Survey (*Bold* dataset; DMMP 2009).
2. Total PCBs were calculated by summing the concentrations of detected PCB congeners.
3. Total cPAHs were calculated by summing the concentrations of all detected cPAH compounds multiplied by their respective PEFs, along with half the reporting limits) of any undetected cPAH compounds multiplied by their respective PEFs.
4. The dioxin TEQ (relative to that of 2,3,7,8-tetrachlorodibenzo-p-dioxin) was calculated by summing the concentrations of detected polychlorinated dibenzo-p-dioxin or furan congeners multiplied by their respective TEFs, along with half the reporting limits of undetected polychlorinated dibenzo-p-dioxin or furan congeners multiplied by their respective TEFs.

a. Only PCB congener data from the OSV *Bold* Survey (DMMP 2009) study were used, as there were few detected values in the Aroclor data.
b. EPA calculated natural background based on the UCL95 using the OSV *Bold* Survey (DMMP 2009) dataset, as presented in the LDW ROD (EPA 2014).

µg – micrograms
ARAR – applicable or relevant and appropriate requirement
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DMMP – Dredged Material Management Program
dw – dry weight
Ecology – Washington State Department of Ecology
EPA – U.S. Environmental Protection Agency
kg – kilogram
mg – milligram
ng – nanogram
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
TEF – toxic equivalency factor
TEQ – toxic equivalent
UCL95 – 95% upper confidence limit on the mean

Natural Background for cPAHs in Sediment

The detection frequency for cPAHs in the OSV *Bold* Survey was 87%, based on quantifying at least one cPAH compound in each sample (Table 4-2). Total cPAHs in each sample were calculated by summing the concentrations of all detected cPAH compounds multiplied by their respective benzo(a)pyrene potency equivalency factors (PEFs), along with half the reporting limits of any undetected cPAH compounds multiplied by their respective PEFs. Concentrations ranged from 1.3 to 57.7 μg TEQ/kg dw, with a mean concentration of 7.1 μg TEQ/kg dw, a 90th percentile of 15 μg TEQ/kg dw. Using the UCL95 of the OSV *Bold* Survey dataset results in a natural background value of 9 μg TEQ/kg dw.

Natural Background for Dioxins/Furans in Sediment

The detection frequency for dioxins/furans in the OSV *Bold* Survey was 100%, based on quantifying at least one congener in each sample (Table 4-2). The total TEQ of dioxins/furans (relative to that of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin) in each sample was calculated by summing the concentrations of certain detected polychlorinated dibenzo-*p*-dioxin or furan congeners multiplied by their respective toxic equivalency factors (TEFs), along with half the reporting limits of undetected polychlorinated dibenzo-*p*-dioxin or furan congeners multiplied by their respective TEFs. Concentrations ranged from 0.23 to 11.6 ng TEQ/kg dw, with a mean of 1.4 ng TEQ/kg dw (Table 4-2), a 90th percentile of 2.2 ng TEQ/kg dw. Using the UCL95 of the OSV *Bold* Survey dataset results in a natural background value of 2 ng TEQ/kg dw.

4.3.3.2 Regional Background in Sediment

Appendix A discusses the justification under SMS for the adjustment of cleanup levels for PCBs and dioxins/furans based on the considerations in WAC 173-204-560(4). Because regional background has not been established for the EW, the PRGs for RAO 1 (based on complying with SMS as an ARAR) are set at the SCO for both PCBs and dioxins/furans (based on natural background).

4.3.4 Role of Practical Quantitation Limits

Both CERCLA and MTCA/SMS allow consideration of PQLs when formulating PRGs to address circumstances in which a concentration determined to be protective cannot be reliably detected using state-of-the-art analytical instruments and methods. For example, if an RBTC is below the concentration at which a contaminant can be reliably quantified, then the PRG for that contaminant may default to the analytical PQL. MTCA defines the PQL as:

> *…the lowest concentration that can be reliably measured within specified limits of precision, accuracy, representativeness, completeness, and comparability during routine laboratory operating conditions, using department approved methods (WAC 173-340-200).*

In simpler terms, the PQL is the minimum concentration for an analyte that can be reported with a high degree of certainty.

Tables 4-3 and 4-4 list the risk driver-specific PQLs developed for the SRI sediment sampling programs and documented in the associated quality assurance project plans. These PQLs represent the lowest values that can be reliably quantified when the sample matrix (in this case, sediment) is free of interfering compounds that can reduce sensitivity and raise reporting limits. Also, these tables present the range of actual sample PQLs reported by the laboratories for the data in the SRI database. These results reflect the range of what the laboratories were able to achieve given the composition of, and matrix complexity associated with, EW OU sediment samples.

Analytical quantitation limits are generally not expected to exceed RBTCs, SQS, or natural background concentrations for samples of low matrix complexity. However, empirical evidence from the SRI suggests that, on a case-by-case basis, matrix interferences have the potential to preclude quantification to concentrations below the PRGs (and ultimately the cleanup levels and standards) established for cleanup of EW OU sediments.

Table 4-3
Preliminary Remediation Goals for Total PCBs, Arsenic, cPAHs, and Dioxins/Furans in Sediment for Human Health and Ecological Risk Driver COCs

	Practical Quantitation Limits		Natural Background	Risk-based Threshold Concentration[a]				Preliminary Remediation Goals		
Analyte	SRI QAPP RLs	Range of RLs from Undetected Values	EPA's Method UCL95	RAO 1: Human Seafood Consumption	RAO 2: Human Direct Contact	RAO 3: Benthic Organisms[b]	RAO 4: Ecological[c]	Value	Basis	Spatial Scale for PRG Application[d]
Total PCBs (µg/kg dw)	4[e]	3.9 – 35[f]	2[g]	2 – 250[h]	NA	NA	39 – 458[i] 100 – >470[i]	2(RAO 1) 250, 370 (RAO 4)[j]	Natural Background (RAO 1); RBTC (RAO 4)	Site-wide
				NA	NA	12/65[k]	NA	12 (mg/kg OC) (RAO 3)	RBTC	Point
Arsenic (mg/kg dw)	0.5	5 – 20	7	NA	3.7	NA	NA	7(RAO 2)	Natural Background	Site-wide
				NA	1.3	NA	NA	7(RAO 2)	Natural Background	Clamming Areas
				NA	NA	57/93[k]	NA	57 (RAO 3)	RBTC	Point
cPAH (µg TEQ/kg dw)	5.9 – 9.5	20 – 48[l]	9	NA[n]	NA	NA[m]	NA	NA	NA	NA
Dioxins/furans (ng TEQ/kg dw)	0.5[o]	NA	2	0.18 – 0.94[p]	NA	NA	NA	2(RAO 1)	Natural Background	Site-wide

Notes:

a. RBTCs developed in the Final SRI (Windward and Anchor QEA 2014).
b. Sediment RBTCs are also included as the SQS and CSL for the remaining 29 risk driver COCs and TBT for the benthic invertebrate community (see Table 4-4).
c. RAO 4 includes RBTCs (based on two LOAEL TRVs; see Section 3.3.1) for protection of English sole and brown rockfish for PCBs.
d. The spatial scale of site-wide exposure is RAO-specific (e.g., seafood consumption for RAO 1 and netfishing for RAO 2 is site-wide, while tribal clamming for RAO 2 is intertidal clamming areas).
e. PCB RLs (as Aroclors) reported; RLs for individual PCB congeners are much lower (0.5 to 1 ng/kg dw).
f. Range of RLs for undetected values were queried from the SRI database and represent RLs for undetected total PCBs. For samples in which none of the individual Aroclors are detected, the total PCB concentration value is represented as the highest RL of an individual Aroclor, and assigned a U-qualifier, indicating no detected concentrations. Individual undetected Aroclors were not reported because they are not included in the calculation of total PCBs when other Aroclors are detected in the sample.
g. Total PCB value based on the sum of detected PCB congeners.
h. The RBTC is less than 1 µg/kg dw at excess cancer risk levels of 10^{-5} and 10^{-6} and for a Hazard Quotient equal to 1; the RBTC range of 2 to 250 µg/kg dw for the three RME seafood consumption scenarios is at the 10^{-4} excess cancer risk level.
i. Values represent the RBTCs for brown rockfish (39 – 458 µg/kg dw) and English sole (100 – >470 µg/kg dw). The value >470 µg/kg dw indicates that even under current conditions in the EW OU (based on an existing sediment SWAC of 470 µg/kg dw), average tissue concentrations are estimated to be less than the upper bound tissue RBTC.
j. As described in Appendix A, the sediment PRG is based on the mean of the RBTC values for each fish receptor. Two PRGs have been established based on brown rockfish (250 µg/kg dw) and English sole (370 µg/kg dw).
k. Total PCB concentration units are mg/kg OC and the two values are SQS/CSL. Arsenic concentration units are mg/kg dw and the two values are SQS/CSL.
l. RLs are based on non-detect samples for individual cPAH compounds with units of µg/kg dw. If none of the individual cPAH compounds were detected, then half the RL was multiplied by the PEF for each compound to calculate the cPAH TEQ RL value.
m. Low- and high-molecular weight PAHs are addressed by the SMS. Criteria are set for both groupings and for individual PAH compounds (see Table 4-4).
n. cPAH PRGs are undefined for the human health seafood consumption pathway (RAO 1). Seafood consumption excess cancer risks for cPAHs were largely attributable to the consumption of clams. There is no consistent relationship, based on site data, relating cPAH concentrations in sediment to concentrations in clam tissue (see Section 8 of SRI; Windward and Anchor QEA 2014). Section 8 of the FS discusses the potential need for future investigations of the sediment/tissue relationship for cPAHs.
o. Dioxins/furans RLs are based on the reporting limits for the individual compounds with units of ng/kg dw.
p. RBTC of 0.18 and 0.94 calculated for adult tribal and child tribal RME scenarios at risk level of 10^{-6} excess cancer risk threshold, respectively.

µg/kg – micrograms per kilogram
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSL – cleanup screening level
dw – dry weight
ng/kg – nanograms per kilogram
OC – organic carbon-normalized
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
PRG – preliminary remediation goal
RL – reporting limit
RME – reasonable maximum exposure
SCO – sediment cleanup objective
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard

Ecology – Washington State Department of Ecology
EPA – U.S. Environmental Protection Agency
FS – feasibility study
LOEAL – lowest-observed-adverse-effect level
mg/kg – milligrams per kilogram
NA – not applicable
QAPP – quality assurance project plan
RAO – remedial action objective
RBTC – risk-based threshold concentration
SRI – Supplemental Remedial Investigation
SWAC – spatially-weighted average concentration
TBT – tributyltin
TEQ – toxic equivalent
TRV – toxicity reference value
UCL95 –- 95% upper confidence limit on the mean

Table 4-4

Preliminary Remediation Goals for Sediment for Benthic Risk Driver COCs

	Practical Quantitation Limit (mg/kg dw)			Risk-Based Threshold Concentrations (RAO 3): Sediment Management Standards (mg/kg dw[a] or mg/kg OC[b]) and TBT[c]		Preliminary Remediation Goal[d]			Detection Frequency		Frequency of Detected concentrations above SQS	
Contaminant	EPA Method	SRI QAPP RLs	Range of RLs from Undetected Values	Sediment Quality Standard (SQS)	Cleanup Screening Level (CSL)	Value	Basis	Spatial Scale of PRG Application	No. of Samples[e]	%	No. of Samples[f]	%
Metals												
Arsenic	EPA 6010B	0.5	6-20[g]	57[a]	93[a]	57[a]	SQS	Point	162/231	70	2/231	0.9
Cadmium	EPA 6010B	0.2	0.2-1.0	5.1[a]	6.7[a]	5.1[a]	SQS		155/231	67	2/231	0.9
Mercury	**EPA 7471A**	**0.05**	**0.04-0.07**	**0.41[a]**	**0.59[a]**	**0.41[a]**	SQS		**233/239**	**98**	**46/239**	**19**
Zinc	EPA 6010B	4.0	NA	410[a]	960[a]	410[a]	SQS		231/231	100	5/231	2.2
PAHs												
2-Methylnaphthalene	EPA 8270D	0.02	0.019 -0.190	38[b]	64[b]	38[b]	SQS	Point	87/240	36	1/240	0.4
Anthracene	EPA 8270D	0.02	**0.019-0.062**	**220[b]**	**1,200[b]**	**220[b]**	SQS		**209/240**	**87**	1/240	0.4
Acenaphthene	EPA 8270D	0.02	**0.019-0.12**	**16[b]**	**57[b]**	**16[b]**	SQS		**126/240**	**53**	**16/240**	**6.7**
Benzo(a)anthracene	EPA 8270D	0.02	0.020-0.061	110[b]	270[b]	110[b]	SQS		226/240	94	7/240	2.9
Benzo(a)pyrene	EPA 8270D	0.02	0.019-0.061	99[b]	210[b]	99[b]	SQS		225/240	94	7/240	2.9
Benzo(g,h,i)perylene	EPA 8270D	0.02	0.019-0.061	31[b]	78[b]	31[b]	SQS		212/240	88	4/240	1.7
Total benzofluoranthenes[h]	EPA 8270D	0.02	0.019-0.061	230[b]	450[b]	230[b]	SQS		228/240	95	7/240	2.9
Chrysene	EPA 8270D	0.02	0.019-0.061	110[b]	360[b]	110[b]	SQS		230/240	96	8/240	3.3
Dibenzo(a,h)anthracene	EPA 8270D-SIM	0.0063	0.019-0.12	12[b]	33[b]	12[b]	SQS		156/240	65	4/240	1.7
Dibenzofuran	EPA 8270D	0.02	0.019-0.190	15[b]	5[b]	15[b]	SQS		107/240	45	8/240	3.3
Fluoranthene	EPA 8270D	0.02	**0.02-0.061**	**160[b]**	**1,200[b]**	**160[b]**	SQS		**233/240**	**97**	**14/240**	**5.8**
Fluorene	EPA 8270D	0.02	**0.019-0.120**	**23[b]**	**79[b]**	**23[b]**	SQS		**144/240**	**60**	**12/240**	**5.0**
Indeno(1,2,3-cd)pyrene	EPA 8270D	0.02	0.019-0.062	34[b]	88[b]	34[b]	SQS		210/240	88	6/240	2.5
Phenanthrene	EPA 8270D	0.02	**0.019-0.061**	**100[b]**	**480[b]**	**100[b]**	SQS		**230/240**	**96**	**15/240**	**6.3**
Pyrene	EPA 8270D	0.02	0.020-0.061	1,000[b]	1,400[b]	1,000[b]	SQS		235/240	98	1/240	0.4
Total HPAHs[i]	EPA 8270D	0.02	0.020	960[b]	5,300[b]	960[b]	SQS		237/240	99	9/240	3.8
Total LPAHs[j]	EPA 8270D	0.02	0.019-0.061	370[b]	780[b]	370[b]	SQS		230/240	96	8/240	3.3
Phthalates												
BEHP	EPA 8270D	0.02	0.020-1.40	47[b]	78[b]	47[b]	SQS	Point	207/231	90	9/231	3.9
BBP	EPA 8270D-SIM	0.0067	0.014-0.190[g]	4.9[b]	64[b]	4.9[b]	SQS		101/231	44	9/231	3.9
Di-n-butyl phthalate	EPA 8270D	0.02	0.019-0.190	220[b]	1,700[b]	220[b]	SQS		32/231	14	1/231	0.4

Table 4-4

Preliminary Remediation Goals for Sediment for Benthic Risk Driver COCs

Contaminant	Practical Quantitation Limit (mg/kg dw)			Risk-Based Threshold Concentrations (RAO 3): Sediment Management Standards (mg/kg dw[a] or mg/kg OC[b]) and TBT[c]		Preliminary Remediation Goal[d]			Detection Frequency		Frequency of Detected concentrations above SQS	
	EPA Method	SRI QAPP RLs	Range of RLs from Undetected Values	Sediment Quality Standard (SQS)	Cleanup Screening Level (CSL)	Value	Basis	Spatial Scale of PRG Application	No. of Samples[e]	%	No. of Samples[f]	%
Other SVOCs												
1,4-Dichlorobenzene	EPA 8270D-SIM	0.0067	**0.0009-0.020**	**3.1[b]**	**9.0[b]**	**3.1[b]**	SQS	Point	**146/231**	**63**	**29/231**	**13**
2,4-Dimethylphenol	EPA 8270D-SIM	0.0067	0.019-0.500[g]	0.029[b]	0.029[b]	0.029[b]	SQS		14/231	6.1	1/231	0.4
n-Nitrosodiphenylamine	EPA 8270D-SIM	0.0067	0.0059-0.190	11[b]	11[b]	11[b]	SQS		2/231	0.90	1/231	0.4
Phenol	EPA 8270D-SIM	0.0067	0.019-0.190[g]	0.42[a]	1.2[a]	0.42[a]	SQS		94/231	41	5/231	2.2
PCBs												
Total PCBs	EPA 8082	**0.5**	0.51-3.4	**12[b]**	**65[b]**	**12[b]**	SQS	Point	**227/240**	**95**	**157/240**	**66**
Tributyltin												
Tributyltin	Krone 1989	**0.004**	**0.0034-0.0037**	**7.5[b,c]**		**7.5[b]**	RBTC	Point	**60/67**	**90**	**10/67**	**0.2**

Bold – indicates the contaminant for which 5% or more of the surface sediment samples had detected concentrations above the SQS.

a. Units are mg/kg dw for these contaminants.
b. Units are mg/kg OC for these contaminants
c. An organic carbon normalized sediment RBTC was calculated in the EW SRI (Windward and Anchor QEA 2014). The frequency of detected concentrations above the RBTC is shown.
d. PRGs are considered on the basis of a point concentration or toxicity test pass.
e. Represents the number of detects per total number of samples.
f. Represents the number of detects > SQS per total number of samples. If any individual sample had a TOC content > 4% or < 0.5% and the dry-weight concentration was > LAET, the concentration was considered to be > SQS.
g. RLs elevated above the QAPP RLs due to analytical dilution and matrix interferences.
h. Total benzofluoranthenes were calculated as the sum of benzo(b)fluoranthene and benzo(k)fluoranthene.
i. Total HPAHs were calculated as the sum of benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.
j. Total LPAHs were calculated as the sum of acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
CSL – cleanup screening level
dw – dry weight
EPA – U.S. Environmental Protection Agency
EW – East Waterway
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
LAET – lowest-apparent-effect threshold
mg/kg – milligrams per kilogram
NA – not applicable
OC – organic carbon-normalized
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
PRG – preliminary remediation goal
QAPP – quality assurance project plan
RAO – remedial action objective
RBTC – risk-based threshold concentration
RL – reporting limit
SQS – sediment quality standard
SRI – Supplemental Remedial Investigation
SVOC – semivolatile organic compound
TBT – tributylin
TOC – total organic carbon

4.4 Preliminary Remediation Goals

When selecting PRG(s) for each RAO, the higher value of the RAO RBTC, background, or PQL is selected. Regional background concentrations have not been established for the EW but Appendix A evaluates the criteria for adjustment of the cleanup level above natural background-based cleanup levels for PCBs and dioxins/furans. PQLs were not found to influence selection of the PRGs (i.e., all PRGs are above SRI PQLs). Following completion of the final FS, upward adjustment of the cleanup level may occur once a regional background concentration is determined for the EW area.[47] The RAOs and PRGs are considered in selecting the RALs in Section 6 of the FS. Section 9 compares estimated concentrations of risk driver COCs following sediment remediation to PRGs as one measure of the effectiveness of the remedial alternatives.

Tables 4-3 and 4-4 summarize the analysis and selection of sediment PRGs for the risk driver COCs. Table 4-3 focuses on the four human health risk driver COCs and the fish risk driver COC, and is subdivided to address the various spatial applications of the PRGs for each RAO. Table 4-4 contains the PRG analysis for the risk driver COCs for RAO 3. PRGs were developed only for risk driver COCs identified in the SRI. The potential for risk reduction for the other COCs following remedial action is evaluated in Section 9.

The PRGs are applied on either a point basis or an average basis over a given exposure area depending on the COC, exposure pathway, and receptor of concern. PRGs for RAOs 1, 2, and 4 are applied on an area-wide average basis that requires a sediment SWAC over the applicable exposure area to be below the PRG. SWACs are calculated following sediment remediation to evaluate and compare remedial alternatives (see Sections 9 and 10); compliance

[47] SCUM II (Ecology 2017) states: "Ecology may consider whether the cleanup level should be adjusted upwards according to the process detailed in Chapter 7, Section 7.2.3. An example of when this may be appropriate is where the cleanup level was established below regional background, but Ecology has since established or approved regional background for the geographic area where the site is located. In this case, Ecology may determine that regional background represents the concentration in sediment that is technically possible to maintain, due to ongoing sources that are not under the authority or responsibility of the PLP. Therefore, Ecology could allow upwards adjustment of the sediment cleanup level to the CSL if regional background has been established as the CSL."

for remedial actions for RAOs 1, 2, and 4 will be based on the UCL95 of post-remediation sampling data. RAO 3 is applied on a point basis for protection of benthic organisms.

For RAO 1, the numerical PRGs for total PCBs and dioxins/furans are set to natural background because the sediment RBTCs[48] for the RME seafood consumption scenarios are below natural background. The natural background concentration is estimated using the EPA methodology. cPAH PRGs were not identified for the human health seafood consumption pathway (RAO 1). Excess cancer risks for cPAHs were largely attributable to the consumption of clams. Based on data collected during the SRI, there is not a significant relationship between cPAH concentrations in sediment and concentrations in clam tissue (Section 8 of the SRI; Windward and Anchor QEA 2014). However, the development and evaluation of remedial alternatives in the latter sections of the FS discuss the potential need for future investigations of the sediment/clam tissue relationships for cPAHs.

For RAO 2, the PRG is based on a comparison between the sediment RBTC (1×10^{-6} excess cancer risk threshold) and background (whichever is higher). RBTCs were developed for two exposure scenarios: netfishing and tribal clamming direct contact (which includes both dermal contact and incidental ingestion) with sediment. The PRG is applied on a spatially-weighted average basis over a given exposure area (e.g., site-wide for the netfishing PRG and over clamming areas for the tribal clamming PRG). The arsenic PRG is based on natural background because the RBTCs at $1 \text{ x } 10^{-6}$ excess cancer risk threshold are below natural background.

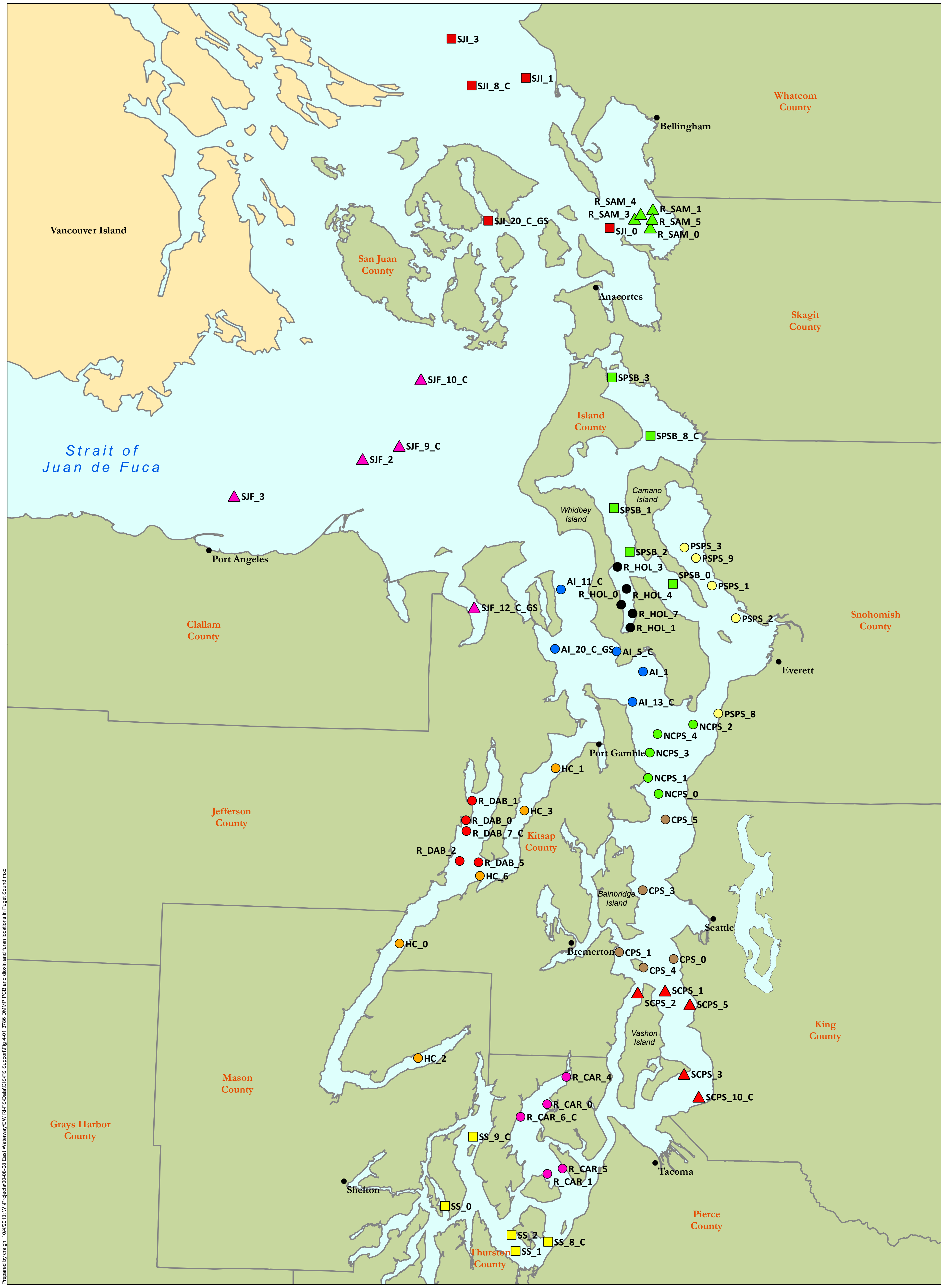
For RAO 3, the SMS numerical criteria for the protection of benthic organisms apply on a point basis (Table 4-4). As noted in Section 4.3.1, WAC 173-204-570(4) specifies that the site-specific cleanup standards shall be as close as practicable to the SCO, but in no case shall exceed the minimum cleanup level (the CSL). For this reason, the PRGs for RAO 3 in this FS

[48] For PCBs, sediment RBTCs were calculated only for the 1×10^{-4} excess cancer risk threshold. The contribution of PCBs in water alone (even at concentrations similar to those in Green River) was high enough to result in seafood consumption risks for Adult and Child Tribal RME and Asian and Pacific Islander RME scenarios exceeding the 1×10^{-6} and 1×10^{-5} excess cancer risk thresholds even in the absence of any contribution from sediment (Table 3-13). For dioxins/furans, sediment RBTCs were below natural background for all RME scenarios for the $1 \text{ x } 10^{-6}$ excess cancer risk threshold.

are set to the SQS (same as the benthic SCO). However, where co-located toxicity test data are available, sediment toxicity results override the numerical criteria for RAO 3. A PRG for TBT is also established for RAO 3 based on the sediment RBTC (Table 4-4).

For RAO 4, PRGs for total PCBs for the protection of fish are based on RBTCs (HQ less than 1). Appendix A details the development of each fish PRG based on available RBTCs. The selected PRGs are shown in Table 4-3).

Predicted post-remedy HQs and risks calculated using the EW food web model-predicted tissue concentrations are presented in Section 9. EPA will establish target tissue concentrations to measure progress toward achieving RAOs 1 and 4 in the ROD. Target tissue concentrations are not cleanup levels; they will be used for informational purposes and to assess ongoing risks to people and ecological receptors.



Puget Sound 2008 Survey Location[a]

- AI
- CPS
- HC
- NCPS
- PSPS
- R_CAR
- R_DAB
- R_HOL
- R_SAM
- SCPS
- SJF
- SJI
- SPSB
- SS

0 12
Miles

[a] Additional details on these sample locations are in the OSV Bold Summer 2008 Survey Data Report (DMMP 2009).

Figure 4-1
Locations of Surface Sediment Data Available for Arsenic, PCBs, cPAHs, and Dioxins and Furans from the Puget Sound 2008 Survey for Natural Background Consideration
Feasibility Study
East Waterway Study Area

5 PREDICTIVE EVALUATION METHODOLOGY FOR SITE PERFORMANCE OVER TIME

This section provides an overview of the information and methodology used to predict site performance over time based on remedial alternatives. Remedial alternatives are described in Section 8, and the results of the evaluations described in this section are provided in Section 9. Sediment transport in the EW was evaluated using site-specific empirical data and modeling and presented in the EW STER (Anchor QEA and Coast & Harbor Engineering 2012). The results of the STER were used to develop the Physical Processes CSM (hydrodynamics and sediment transport) provided in the EW SRI (Windward and Anchor QEA 2014). Additional analyses conducted following approval of the EW SRI resulted in modifications to the Physical Processes CSM, as described in the SRI, related to variable net sedimentation rates within the EW and estimates of the site-wide net sedimentation rate for the EW. These additional analyses are documented in Appendix J. The understanding of sediment transport in the EW developed through the STER, SRI, and these additional analyses are used in this FS to inform development of remedial alternatives and to evaluate site performance over time after remediation.

Section 5.1 provides a summary of information from the STER, SRI, and additional analyses conducted following approval of the SRI, that are pertinent to the evaluations described in this section. This information includes a general overview of sediment transport within the EW, detailed information on solids loads to the EW, mass balance of solids within the EW, net sedimentation rates in the EW, and erosion potential of sediments within the EW due to currents and vessel movements. In-depth discussion of the additional analyses conducted after publication of the Final SRI are provided in Section 2 of Appendix J.

Sections 5.2 through 5.5 describe the purpose for and methodology used to evaluate site performance over time in the EW. The site performance evaluation is divided up into separate assessments as follows:

- Post-construction Sediment Bed Replacement Values and Dredge Residuals (Section 5.2)
- Site-wide Evaluation of Site Performance Over Time (Section 5.3)
- Recontamination Potential Evaluation (Section 5.4)
- Point Mixing Model for Evaluation of RAO 3 (Section 5.5)

A summary outlining sources of uncertainty in this evaluation is provided in Section 5.6. The mathematical basis for the analyses summarized in this section and how uncertainties influence the results of the site performance evaluations are provided in Appendix J.

5.1 Overview of Sediment Transport in the East Waterway

This section provides an overview of sediment transport processes in the EW, as outlined in the Physical Processes CSM developed as part of the SRI (Windward and Anchor QEA 2014) and further refined in additional analysis conducted after formal approval of the SRI.

Sediment sources to the EW include the upstream sources (Green River, LDW bed and bank sediments, and LDW laterals), downstream sources (Elliott Bay), and lateral sources that discharge within the EW. Geochronology cores were collected in the EW to evaluate net sedimentation rates (Anchor QEA and Coast & Harbor Engineering 2012). Cores were placed in areas that had not been recently dredged[49] (see Figure 2-22), and in areas representative of different hydrodynamic regimes (Anchor QEA 2009). Cores were not collected in the Deep Main Body Reach between Stations 2800 and 5000 because this area had been recently dredged. Figure 5-1 shows the locations of each of the 22 geochronology cores attempted, the 18 cores recovered, and the 4 cores that could not be recovered.

The evaluation of the 18 recovered geochronology cores (see Figure 5-1 herein, and SRI Maps 3-11a and 3-11b; Windward and Anchor QEA 2014) suggests that the majority of the Shallow and Deep Main Body Reaches (between Stations 2800 and 6800) and the interior of Slip 27 (Figure 5-1) are net depositional. Net sedimentation rates measured for recoverable cores in these areas range from 0.1 to greater than 4.2 cm/yr based on lead-210 (Pb-210) and cesium-137 (Cs-137) data. There was one core (GC-17) in the Shallow Main Body Reach at the Olympic Tug and Barge berth that may have no recovery due to sands and gravels on the seabed in that location. This result suggests that the area around GC-17 has little to no net deposition due to the influence of vessel operations in that area.

[49] Dredged areas within the EW were expected to have unreadable data for the Cs-137 peak due to the depth of sediment below mudline removed during dredging actions likely removed the Cs-137 peak.

Cores recovered and evaluated in the Deep Main Body Reach between Stations 0 and 2800 suggest that this area is net depositional but influenced by localized episodic mixing and/or erosion events due to propwash from vessel operations. Recovered and evaluated cores in this area did not have a clear Cs-137 peak, which implies that mixing occurred in the past or could be occurring in this area due to vessel operations (propwash). Evaluation of Pb-210 data in these cores did provide an estimate for net sedimentation rates in these areas averaging approximately 0.5 cm/yr. There was one core (GC-04) in the Deep Main Body Reach along the T-18 berth that had no recovery due to sands and gravels on the seabed in that location. As with the area adjacent to the Olympic Tug and Barge berth, this result suggests that the area around GC-04 may have no net deposition due to the influence of vessel operations in that area. Sediment in underpier areas is also expected to have deposition of sediments from upstream and lateral sources and be subject to periodic erosion and resuspension due to impacts from propwash and bow and stern thrusters.

Since geochronology cores were not retrieved in the Sill and Junction Reaches due to presence of consolidated sand and gravel surface sediments, the Sill and Junction Reaches may not be net depositional in the areas where geochronological cores were attempted. Results of the sediment transport modeling (QEA 2008) completed for the LDW FS (AECOM 2012) and modeling results from the PTM for lateral sources within the EW (Anchor QEA and Coast & Harbor Engineering 2012) completed for the SRI/FS suggest that 99% of the incoming suspended sediment to the EW is from the Green River, approximately 0.7% is from the LDW (bed sediments and lateral inputs), and less than 0.3% is from lateral inputs directly discharging to the EW itself. The sediment inputs into the EW from Elliott Bay are assumed to be small relative to upstream and EW lateral source inputs based on existing studies of sediment transport in Elliott Bay and comparison of total suspended solids (TSS) in Elliott Bay and the LDW (see Section 3.1 of the EW SRI; Windward and Anchor QEA 2014).[50] Therefore, sediment loads from Elliott Bay were not included in the analysis.

Comparing modeled estimates of sediment loads and average values of net sedimentation rates in the EW (measured from recovered geochronology cores), between 25% and 60% of

[50] Therefore, sediment inputs to the EW from Elliott Bay were not considered for the modeling efforts; see Sections 5.3 and 5.4.

the incoming suspended sediment is estimated to deposit in the EW, and between 40% and 75% of the incoming suspended sediments is estimated to leave the EW, most likely moving out into Elliott Bay and other locations in Puget Sound (Section 3.4 in the EW SRI; Windward and Anchor QEA 2014). Initial mass deposition patterns within the EW from local lateral sources (evaluated through the PTM discussed in Appendix B, Part 1) show that the majority of initial deposition occurs close to the outfall locations, with relatively little deposition occurring in the deeper areas of the EW.

Riverine and tidal currents in the EW are not expected to cause significant erosion of in situ bed sediments, as the maximum predicted bed shear stress for a 100-year high-flow event is modeled to be less than the critical shear stress[51] of the bed sediments (estimated from site-specific SEDflume data). Modeled bed shear stress due to vessel operations suggests that bed sediments in the Deep Main Body Reach, the Shallow Main Body Reach, and the Junction Reach are subject to episodic erosion and resuspension of bed sediments due to propwash activity.

5.1.1 Sources of Solids Input to the East Waterway

Sediment sources to the EW quantified for the purposes of the FS include upstream sources (Green River, LDW bed sediments, and LDW laterals) and local lateral sources (e.g., stormwater and CSO discharges) that drain directly to the EW.

Based on results of the LDW sediment transport model (QEA 2008), the total estimated sediment/solids load transported from the Green River and the LDW to the junction prior to the split between EW and WW over the 30-year simulation was 3,241,390 metric tons, with 3,215,850 metric tons from the Green River (99.2% of total), 7,840 metric tons from eroded bed sediments from river flows within the LDW (0.2% of total), and 17,770 metric tons from LDW lateral sources (0.6% of total) (AECOM 2012). Results from the LDW sediment transport model (QEA 2008) indicate that essentially 100% of the incoming upstream load to

[51] In this report, critical shear stress is defined as a property of the in situ bed sediments. It represents the value of shear stress (applied to that bed due to current velocities) at which the bed sediment would begin to mobilize (e.g., erode).

the EW from the Green River and LDW (bed sediments and lateral inputs) consist of silts and clays.[52] The percentage of flow from the LDW that enters the EW was evaluated in the EW STER (Anchor QEA and Coast & Harbor Engineering 2012) as varying between 50% (for 2-year flows and below) and 30% (for flows greater than the 2-year event). Assuming that the split in suspended sediment load between the EW and WW follows the split in flow, and using the average mass per year (over the 30-year simulation time of the LDW model), the annual average sediment loads transported into the EW from upstream are predicted to be as follows:[53]

- Green River source: 32,159 to 53,598 metric tons per year[54]
- Eroded bed sediments in the LDW: 78 to 131 metric tons per year
- Lateral sources within the LDW: 178 to 296 metric tons per year

Solids inputs to the EW from local lateral sources include contributions from SDs, CSOs, and runoff from the adjacent bridges and port aprons (see FS Figure 2-1 and Figure 2 of Appendix B, Part 1). Current conditions solids loading (annual) for EW lateral sources was estimated as part of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012). Annual solids loading from EW lateral sources based on likely future source control actions were developed as part of the FS and are discussed in Appendix B, Part 1. Future source control actions that will result in reduced solids loadings from lateral sources include CSO Control Plans that include both treatment and reduction in flow. A base case and low and high bounding cases for annual solids loads were estimated for both current and future conditions for EW lateral sources. Based on these bounding cases, the range of annual solids load to the EW from EW lateral sources is as follows:

- Current conditions: 45 to 114 metric tons per year
- Future conditions: 21 to 80 metric tons per year

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[52] This assumption was made based on results of the LDW sediment transport model (QEA 2008), which predicts that effectively all of the upstream sediment load input to the EW consists of fine particles (silts and clays), which should be well distributed in the water column.

[53] This estimate is not quantifying what settles in the EW from upstream; only a portion of these solids will settle in the EW.

[54] Range in values based on range in the estimated split in flow between the EW and WW; 30% to 50% of flow from LDW to EW.

5.1.2 Net Sedimentation Rates

Net sedimentation rates[55] were estimated as part of the FS using geochronology core samples and the predicted scour within the vessel operational areas defined as part of the EW STE and shown in Figures 5-1 and 5-2. Evaluation to determine the net sedimentation rate in the EW conducted as part of the EW STE and EW SRI was updated during the FS, and the revised net sedimentation rates for the EW are documented herein.

Geochronology core sampling included field collection of subsurface sediment cores from 22 locations located throughout the EW, and testing for Cs-137 and Pb-210 (Figure 2-13). Cores were placed in areas that had not been recently dredged, and in areas representative of different hydrodynamic regimes (Anchor QEA 2009). The geochronology core collection effort resulted in 18 recovered cores (including Core GC-20, which had low recovery) and four cores that had no recovery due to surface sediment conditions (i.e., gravel) at those locations (GC-4, GC-17, GC-21, and GC-22). The unrecovered cores were located adjacent to the Olympic Tug and Barge facility and T-18 in the Main Body Reach, along the center line of the Junction Reach, and within the Sill Reach of the EW (see Figure 5-1).

The geochronology analysis was done by evaluating the vertical profiles of Cs-137 and Pb-210 activities, which are used to age-date sediments and estimate net sedimentation rates in estuarine and freshwater systems (Olsen et al. 1978; Orson et al. 1990). Net sedimentation rates estimated from recovered cores[56] using these methods are provided in Table 3-3 of the EW SRI (Windward and Anchor QEA 2014). A summary of net sedimentation rates is provided below:

- Net sedimentation rates estimated from recovered cores using Cs-137 data range from 1.1 to greater than 2.0 cm/yr, with an average of 1.6 cm/yr. The range of sedimentation rates estimated from Cs-137 data for individual cores was relatively narrow compared to the Pb-210 data, and is therefore considered less uncertain than the Pb-210 data, when it was available.

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[55] The net sedimentation rate is the rate of sediment deposition (cm/yr), taking into account erosion and accretion processes at the site.

[56] Some recovered cores (GC-01, GC-03, GC-06, and GC-07) were archived and were not analyzed based on discussions with EPA, as documented in the EW SRI (Windward and Anchor QEA 2014).

- Net sedimentation rates estimated from recovered cores using Pb-210 data range from 0.1 to 4.2 cm/yr, with an average of 0.5 cm/yr. The range of sedimentation rates estimated from Pb-210 data for individual cores was greater than from Cs-137 data, and is therefore considered more uncertain than the Cs-137 data, when both estimates were available.
- The average net sedimentation rate from recovered cores is 1.6 cm/yr based on Cs-137 data, and 0.5 cm/yr based on Pb-210 data.
- Areas where cores were not recovered are assumed to have a net sedimentation rate of 0 cm/yr (no net sedimentation).

Spatially variable net sedimentation rates within the EW were assigned based on the vessel operational areas (defined in the STE) and geochronology core data. Figure 5-1 shows the locations of the vessel operational areas, geochronology cores (both recovered and unrecovered), and the representative net sedimentation rate assigned to each area. Representative net sedimentation rates were defined for each area based on the following methodology:

- Each vessel operational area was assigned a representative net sedimentation rate of 0 cm/yr, 0.5 cm/yr (average of recoverable cores for Pb-210 data), or 1.6 cm/yr (average of recoverable cores for Cs-137 data).
- Vessel operational areas that had recoverable cores within the area were assigned one of the representative net sedimentation rates based on those core data.
- If Cs-137 data were available within the vessel operational area, then net sedimentation rates were chosen using that data. Vessel operational areas that had no Cs-137 data peak measured were assigned a representative net sedimentation rate based on the Pb-210 data. Cs-137 data were prioritized over Pb-210 data due to higher uncertainty in Pb-210 data analysis for net sedimentation rate.
- Vessel operational areas that did not have any cores attempted within them, or had archived cores that were not analyzed, were assigned one of the representative net sedimentation rates based on adjacent areas, also considering other lines of evidence (e.g., estimated vessel scour). Similar to areas where cores were collected, the average of the Cs-137 data were prioritized over the average of the Pb-210 data due to higher uncertainty in Pb-210 data analysis for net sedimentation rate.
- If an unrecovered core was located in a vessel operational area (and no recovered cores were located within that area), the area was assigned a 0 net sedimentation rate.

- If an unrecovered core and a recovered core were located within the same vessel operational area, best professional judgement was used to assign an appropriate representative net sedimentation rate for that area.
- Estimated vessel scour depths associated with patterns of vessel use (Figure 5-2) and bathymetry (Figure 2-3b) were also used as a line of evidence for distinguishing net sedimention rates in adjacent operational areas.

Table 5-1 provides a summary of net sedimentation rates defined for each vessel operational area using the above approach.

For use in the predictive modeling efforts (Section 5.3 and 5.4) a site-wide net sedimentation rate was estimated based on the individual core net sedimentation rates. The site-wide net sedimentation rate for the EW FS of 1.2 cm/yr was estimated based on an area-weighted average of the representative net sedimentation rates for each vessel operational area shown in Figure 5-1 and listed in Table 5-1.

There is uncertainty in the assumption of average net sedimentation rate in the EW based on the range of net sedimentation rates measured by geochronology cores, impacts of vessel operations within the EW, and the methodology used to assign representative net sedimentation rates to each vessel operational area. The impacts of the uncertainty in the assumption for average net sedimentation rate on the results of the FS evaluation of site performance over time are evaluated through a sensitivity and bounding analyses described in Appendix J.

Table 5-1
Net Sedimentation Rates Defined by Vessel Operational Area

Propwash Area	Area (square feet)	Geochronology Cores Located in Area	Net Sedimentation Rate (in cm/yr) Range Based on Cs-137 Data (see Table 3-3 in EW SRI[a])			Net Sedimentation Rate (in cm/yr) Range Based on Pb-210 Data (see Table 3-3 in EW SRI[a])			Net Sedimentation Rate Assigned[b,c] (cm/yr)	Basis
			Via Cs-137 Peak	Low	High	Estimate Based on Best-Fit Line	Low	High		
1A-1	273,332	None	No Data (previously dredged area)			No Data (previously dredged area)			1.6	Average of the Cs-137 data, consistent with adjacent area (Area 5).
1A-2	286,107	None	No Data (previously dredged area)			No Data (previously dredged area)			1.6	Average of the Cs-137 data, consistent with adjacent areas to the south and moderate propeller wash forces in this area compared to Area 1A-3 (which has higher propeller wash forces; Figure 5-2).
1A-3	283,699	GC-08	No Peak			0.28	0.20	0.49	0.5	Average of the Pb-210 data, due to core GC-08 having Pb-210 data but no Cs-137 peak. In addition, the area is adjacent to the area with no recovery (Area 1A-4), but no bathymetric evidence of sediment propeller wash is present in this area (Figure 2-3b).
1A-4	271,317	GC-03	Archived			Archived			0	Net sedimentation rate set to 0 due to both an unrecovered core (GC-04) and predicted high scour rates from propeller wash in this area (Figure 5-2). This is also consistent with bathymetric evidence of propeller wash (Figure 2-3b).
		GC-04	Unrecovered			Unrecovered				
		GC-06	Archived			Archived				
1A-5	224,452	GC-01	Archived			Archived			0.5	Average of the Pb-210 data, due to the area having a recoverable core (which was archived), being adjacent to the area with no recovery (Area 1A-4), and having similar predicted propeller wash forces as Areas 1A-3 and 1A-4. No bathymetric evidence of sediment propeller wash is present in this area (Figure 2-3b).
1A-6	415,855	None	No Data (previously dredged area)			No Data (previously dredged area)			1.6	Average of the Cs-137 data, consistent with adjacent areas. This area is predicted to have propeller wash forces similar to Areas 1A-1, 1A-2, and 4A (Figure 5-2).
1B-1	870,200	GC-07	Archived			Archived			1.6	Average of Cs-137 data. Area 1B-1 had a recoverable core (which was archived) and is part of the navigation channel servicing T-18 Berths 3 and 4 (Areas 1A-1 and 1A-2), T-30 (Area 1A-6), T-25 (Area 4A), and Slip 27 (Area 3), and therefore is assigned the same sedimentation rate as these areas.
1B-2	870,200	GC-05	No Peak			0.67	0.26	0.67	0.5	Average of the Pb-210 data, due to core GC-05 having Pb-210 data but no Cs-137 peak. In addition, the area is part of the navigation channel that services the larger vessels that use T-18 Berths 1 and 2 (Areas 1A-3 through 1A-5), and therefore is assigned the same sedimentation rate as these areas that also have recoverable cores (i.e., Areas 1A-3 and 1A-5).
1C	403,971	None	No Data			No Data			1.6	Average of Cs-137 data, because sedimentation rate is consistent with adjacent areas to the north and south, and Area 1C is not expected to have large propeller wash forces compared to T-18 Berths 1 and 2 and the adjacent navigation channel (Figure 5-2).
2	301,364	GC-02	No Peak			Low Correlation			1.6	Average of Cs-137 data, consistent with Area 3 (another slip) that suggests selection of a higher range net sedimentation rate for this area.
3	215,033	GC-09	No Peak			0.56	0.35	1.4	1.6	Average of Cs-137 data. Cs-137 and Pb-210 data in this area suggest selection of a higher range net sedimentation rate for this area.
		GC-10	1.3	1.2	1.4	0.61	0.3	0.61		
4A	359,473	GC-13	No Peak			0.69	0.34	0.69	1.6	Average of Cs-137 data. Although core GC-13 only had a Pb-210 peak, the area is expected to have a higher sedimentation rate due to proximity to the narrow to wide waterway transition and the data in adjacent Areas 4B and 6-2. Cs-137 data used because nearby core GC-12 includes Cs-137 sedimentation rates but has a lower Pb-210 sedimentation rate than core GC-13, indicating the sediment rates are similar in these two areas (i.e., Areas 4B and 4A).
4B	412,584	GC-12	>1.9	1.8	2.0	0.46	0.27	1.8	1.6	Average of Cs-137 data due to Cs-137 peak.
		GC-16	1.6	1.2	1.4	Low Correlation				
5	356,623	GC-11	>1.7	1.6	1.8	0.47	0.27	1.8	1.6	Average of Cs-137 data due to Cs-137 peak.
		GC-15	1.3	1.1	1.3	Low Correlation				

Table 5-1

Net Sedimentation Rates Defined by Vessel Operational Area

Propwash Area	Area (square feet)	Geochronology Cores Located in Area	Net Sedimentation Rate (in cm/yr) Range Based on Cs-137 Data (see Table 3-3 in EW SRI[a])			Net Sedimentation Rate (in cm/yr) Range Based on Pb-210 Data (see Table 3-3 in EW SRI[a])			Net Sedimentation Rate Assigned[b,c] (cm/yr)	Basis
			Via Cs-137 Peak	Low	High	Estimate Based on Best-Fit Line	Low	High		
6	181,099	GC-17	Unrecovered			Unrecovered			0.5	Average of Pb-210 data. Cs-137 data from core GC-18 suggests a higher net sedimentation rate, but core GC-17 was unrecoverable in this area, which suggests a moderate net sedimentation rate.
		GC-18	>1.9	1.8	2.0	Low Correlation				
		GC-20	Low Recovery			Low Recovery				
6-2	66,247	GC-16	1.6	1.5	1.7	0.18	0.09	4.2	1.6	Average of Cs-137 data due to Cs-137 peak.
7	86,233	GC-19A	1.2	1.1	1.3	Low Correlation			1.6	Average of Cs-137 data due to Cs-137 peak.
8	93,598	GC-21	Unrecovered			Unrecovered			0	Net sedimentation rate set to 0 due to two unrecovered cores in area.
		GC-22	Unrecovered			Unrecovered				

Notes:

a. East Waterway (EW) Supplemental Remedial Investigation (SRI) (Windward and Anchor QEA 2014).

b. One of three values were assigned to each of the areas: 0 cm/yr, 0.5 cm/yr, or 1.6 cm/yr, representing no sedimentation, moderate sedimentation based on the average of Pb-210 data, and higher sedimentation based on the average of Cs-137. As discussed in Section 5.1.2, the Cs-137 data are considered more reliable than the Pb-210 and serve as the default in areas without additional data. Shading in the table matches shading in net sedimentation areas shown in Figure 5-1.

c. Site-wide area-weighted net sedimentation rate is 1.2 cm/yr.

cm/yr – centimeters per year   Cs-137 – cesium-137   Pb-210 – lead-210   T – Terminal

5.1.3 Solids Balance Into and Out of the East Waterway

A numerical sediment transport model that evaluates fate and transport of both upstream and EW lateral sources was not developed as part of the EW STER due to the impacts of vessel operations on localized sediment transport in the EW (Anchor and Battelle 2008). Therefore, using estimates of upstream and EW lateral solids loading into the EW (Section 5.1.1) and the average net sedimentation rate in the EW developed from geochronological core data (Section 5.1.2), an estimate of the amount of solids from upstream settling into, and passing out of (i.e., solids mass balance), the waterway was made. This information was used as input to the site performance evaluation. The impacts of the uncertainties associated with estimates of upstream solids loading to the EW on the results of the evaluation are discussed in Appendix J.

In order to estimate the solids mass balance for upstream inputs, a series of steps were undertaken. First, hypothetical net sedimentation rates were calculated assuming that the entire incoming solids load (from upstream and lateral sources within the EW) settled evenly in the EW (including Slips 27 and 36). The total mass loading from upstream and lateral sources into the EW is between approximately 32,500 and 54,176 metric tons per year.[57] This total is based on the 30% to 50% proportion of the total LDW flow predicted by the hydrodynamic model to flow into the EW.[58] The mass load into the EW was converted to a volume by setting the density of the incoming sediment load to the average in situ surface sediment densities measured by the SEDflume core evaluation (1.5 grams per cubic centimeter [g/cm^3]; Anchor QEA and Coast & Harbor Engineering 2012). This mass was then evenly distributed over the entire EW to calculate a hypothetical net sedimentation rate representing a 100% solids retention in the EW. Net sedimentation rates estimated in this manner range between 3.6 and 6.0 cm/yr. The site-wide average net sedimentation rate calculated for the EW (see Section 5.1.2),1.2 cm/yr, was subtracted from these hypothetical sedimentation rates to estimate the percent of incoming solids load that is likely transported out of the EW. This calculation suggests that between 67% and 80% of the sediment load

[57] This is the range in upstream sediment load with the solids load developed for the PTM (current conditions) added.

[58] This assumes that the suspended solids load is the same as the split in flow between EW and WW.

that enters the EW is transported out of the EW and, conversely, that 20% to 33% of the incoming sediment load is retained within the EW.

5.1.4 Scour Potential from High Flow Events

As part of the EW STE, SEDflume cores were collected to evaluate the critical shear stress of surface sediments within the EW.[59] The range in critical shear stresses in the EW based on the 95% confidence interval for the SEDflume data evaluation is 0.20 to 0.37 Pascals (Pa).

Scour potential from high flow events was evaluated as part of the EW STE using critical shear stress values estimated from SEDflume data and bed shear stresses estimated from hydrodynamic model results from the hydrodynamic model simulations completed as part of the EW STE.[60] These estimates of bed shear stress were compared to critical shear stress estimates of in situ sediments obtained from SEDflume cores to evaluate erosion potential within the EW due to tidal and riverine currents based on a typical spring tide and mean annual flows through the 100-year upstream flow event (upstream flow rate of 12,000 cfs). The calculated maximum values of bed shear stress ranged from 0.05 Pa for mean annual upstream flow to 0.12 Pa for the 100-year upstream flow event.

Because the maximum bed shear stress predicted by the model for all flow events is at least 35% below the lower confidence bound value for critical shear stress (0.20 Pa) as estimated from the SEDflume core data, it is anticipated that significant bed scour or erosion of in situ bed sediments within the EW will not occur as a result of tidal or riverine currents.

5.1.5 Scour Potential from Vessel Operations

The majority of the EW is subject to vessel operations that impact bed sediment movement. As part of the EW STER, a study was conducted to define typical and extreme vessel operations in the EW and develop estimates of maximum near-bed velocities and associated bed shear stresses within the EW due to vessel operations. The results and assumptions associated with the vessel operation study (including operational areas and vessel

[59] See Section 6.1.3 of the STER (Anchor QEA and Coast & Harbor Engineering 2012).

[60] See Section 6.2.1 of the STER (Anchor QEA and Coast & Harbor Engineering 2012).

information) are provided in Section 5.1.2 of the STER (Anchor QEA and Coast & Harbor Engineering 2012).

As part of the FS, the calculated bed shear stresses associated with vessel operations (Anchor QEA and Coast & Harbor Engineering 2012) were used to estimate scour depths within the EW. Propwash-induced bed shear stresses due to steady state[61] docking procedures estimated for all defined vessel operations and associated operational areas in the EW range from 2 to 23 Pa. The 95th percentile confidence interval of critical bed shear stress for surface sediments in the EW (from SEDflume core data) ranges between 0.20 and 0.37 Pa. Based on the scour evaluation in the STER (Section 5.1), surface sediments within the waterway have the potential to be eroded due to vessel operations at varying depths ranging from 0.3 to 4.7 feet (based on both typical and extreme vessel operations) throughout the majority of the EW. Scour estimates were calculated using steady state assumptions, and represent conservatively high estimates of scour based on defined vessel operations (see Section 5.1.2 of the STER).

Table 5-2 provides a summary of maximum near bed velocities, bed shear stresses, and predicted scour depths within the EW for the various vessel operational areas. Figure 5-2 shows the spatial variation of predicted scour depths within the EW and identifies the locations of the various vessel operational areas identified in Table 5-2. Additional information on the scour calculations are described in a technical memorandum included in Appendix B, Part 2 of this FS.

[61] For evaluating potential shear stresses and scour depths associated with propwash, it was conservatively assumed that the propwash was "steady state"; the propwash reached the maximum velocity over the largest area.

Table 5-2
Predicted Maximum Bed Shear Stress and Scour Depths Due to Vessel Operations

Vessel Operating Area[1]	Dominant Vessel Operations in Area[1]	Maximum Near-bed Velocity[2] (ft/s)	Maximum Bed Shear Stress[2] (lb/ft^2(Pa))	Maximum Predicted Scour Depth[3,4] (ft)
Areas 1A-3, 1A-4, and 1A-5 (Terminal 18: Berths 1 and 2)	Berthing, large container vessels	11.4	0.48 (23)	4.7
Areas 1A-1, 1A-2, and 1A-6 (Terminal 18: Berths 3 and 4 and portions of Terminal 30)	Berthing, small container vessels	7.1	0.19 (9)	2.8
Areas 1B-1 and 1B-2[5]	Transit in Federal Navigation Channel	3	0.03 (2)	2.8 – 4.7
Area 1C	No berthing area	3	0.03 (2)	0.3
Area 2 (Slip 36)	Berthing, U.S. Coast Guard vessels	6.5	0.16 (8)	2.3
Area 3 (Slip 27)	Barge/tug operations	3	0.03 (2)	0.7
Area 4A (existing operations)	Barge/tug operations	3	0.03 (2)	NA
Area 4A (future operations)	Berthing, small container vessels	9.0	0.30 (14)	2.8
Area 4B	Transit in Federal Navigation Channel	3	0.03 (2)	0.7
Area 5	Berthing, smaller bulk carriers	3	0.03 (2)	0.7
Area 6	Barge/tug operations	10.6	0.45 (22)	2.9
Area 7	Barge/tug operations, no berthing area	4.7	0.08 (4)	0.9
Area 8	Berthing, tugs (no commercial operations)	4.2	0.07 (3)	1.1

Notes:
1. Vessel operating areas and detailed operations information can be found in Section 5.1.2 and Table 5-2 of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012).
2. Calculations for maximum near-bed velocities and shear stresses are discussed in Section 5.1.4 of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012).
3. Calculations for maximum predicted scour depth are provided in Appendix B, Part 2.
4. Predicted scour depths throughout the EW are shown in Figure 5-2.
5. Area 1B represents the navigation area between Terminal 18 and 30 berthing areas. Since berthing maneuvers may begin within the navigation channel depending on weather or other site conditions, this area is expected to experience similar scour depths as the berthing areas.

EW – East Waterway
ft/s – feet per second
lb/ft^2 – pounds per square foot
NA – not applicable
Pa – Pascals
STER – Sediment Transport Evaluation Report

5.2 Post-construction Sediment Bed Replacement Value and Dredge Residuals

The sediment replacement value represents the post-construction surface sediment bed concentration in the biologically active zone (BAZ; top 10 cm) following remediation in the EW. The replacement value is used to derive SWACs, which are used to derive an initial surface sediment concentration for evaluating the site performance over time (Section 5.3) and recontamination potential associated with each alternative (Section 5.4). The replacement value only represents the initial (or Time 0) sediment condition following completion of all remedial construction activities; that is, dredging and placement of residuals management cover (RMC), capping, or ENR. The need for RMC placement will be determined based on post-dredge monitoring, but is assumed for modeling purposes to be placed over all of the dredging area plus immediately adjacent areas (see Section 2 of Appendix B, Part 3A).

Experience at other sediment remediation sites has shown that contaminant concentrations in the sediment bed after completing a remedial action (e.g., dredging or partial dredging and capping) cannot be assumed to be zero (NRC 2007; EPA 2005). This occurs because of several factors: 1) residual surface contamination always exists from the resettling of contaminated sediments suspended during remedial activities; and 2) material used for RMC following dredging may contain low concentrations of key risk driver COCs. In addition, as described in Section 5.1.5, propwash from large ships in the EW will also mix dredge residuals, RMC, and existing sediments around the site.

Detailed evaluation and calculated values of dredge residuals and associated bed replacement values for dredging activities and other proposed remedial technologies are provided in Part 3A of Appendix B.

5.3 Site-wide Evaluation of Site Performance Over Time

The evaluation of the site performance over time will be based on predictions of the concentrations of human health risk driver COCs in surface sediment over time following remediation due to future sediment deposition and vertical mixing processes. The long-term surface sediment predictions will provide information to assess whether the remedial alternatives are likely to remain effective at meeting RAOs. These long-term predictions take into account upstream and lateral inputs to the EW. This evaluation will be used to predict whether the EW remedial alternatives remain effective in the long term (e.g., 10, 20, and 30 years post-construction) at meeting human health and ecological RAOs.

The site performance over time evaluation will be used to predict changes to the EW site-wide SWAC[62] (from Time 0 as determined in the short-term effectiveness evaluation) over time (years 1 through 40) for the four human health risk driver COCs (total PCBs,[63] arsenic, cPAHs, and dioxins/furans) for each remedial alternative based on anticipated solids deposition and vertical mixing (from propwash and bioturbation) in the EW. This evaluation will be referred to as the box model evaluation. Only these four risk drivers will be analyzed in this way because their compliance is measured as a site-wide average concentration.

The SWAC after construction completion and over time is dependent on remedial alternative, physical processes within the EW, and upstream and lateral inputs to the EW. Specific elements that were considered for the box model evaluation include the following:

- Time 0 surface sediment chemistry based on proposed alternatives, including replacement values for remediated and interior unremediated areas (Section 5.2), along with current sediment bed concentrations in other areas, such as underpier and areas below RALs along the north and south boundaries of the OU).
- Bed mixing depths due to propwash and bioturbation (varies within the EW). Armor rock and sediment protected by armor rock in the various alternatives are assumed not to mix.
- An assumed average net sedimentation rate within the EW determined from geochronology core data (see Section 5.1.2). For the purpose of evaluation of site-wide SWAC values, a constant value was applied for the entire EW, and all solids sources to the EW are assumed to settle evenly throughout the EW. This simplifying assumption is appropriate for calculating site-wide average concentrations within the EW.

[62] Spatially-weighted average concentrations (SWACs) are average concentrations in an area of interest calculated by interpolating data over a specified area such that each individual concentration value is weighted in proportion to the sediment area it represents. SWACs are used to estimate exposure point concentrations to assess risk to human or ecological receptors and for estimating the effectiveness of the alternatives at reducing that risk.
[63] Total PCBs are also a risk driver COC for fish and will be assessed on a site-wide basis like the human health COCs based on seafood consumption.

- Contribution to net sedimentation rate in the EW from EW lateral sources and upstream sources (Green River, LDW bed sediment, and lateral inputs).
- Chemistry for each input: bed replacement value for remediated areas, unremediated area, Green River, LDW bed sediment and lateral sources, and EW lateral sources.

The effects of future dredging activities were not taken into account in this evaluation because the need, location, and timing of maintenance dredging activities are unknown and may vary over time. In addition, the purpose of the evaluation is to compare the relative performance of the remedial alternatives against each other. Maintenance dredging activities are expected to have similar effects on all proposed alternatives.

Specific calculations for each alternative include three specific evaluations as follows:

- Incoming Solids Concentrations: Estimate total solids loading to the EW from upstream and lateral sources and their corresponding chemical concentrations
- Define Site-wide Surface Sediment SWAC (years 1 to 40): SWAC covering the entirety of the EW OU
- Define Site-specific Surface Sediment SWAC in Target Areas (years 1 to 40): Underpier and intertidal clamming areas

These evaluations are described in more detail in the following sections. Uncertainty associated with input values and methodology on the results of the box model evaluation is discussed in Appendix J.

5.3.1 Chemistry Assumptions for Upstream and East Waterway Lateral Sources

Chemistry assumptions for upstream (Green River, LDW bed sediment, and LDW lateral sources) and EW lateral sources were developed for the four human health risk driver contaminants (total PCBs, cPAHs, dioxins/furans, and arsenic) evaluated as part of the box model evaluation.

Chemistry assumptions for Green River input considered the same datasets for use in the LDW (AECOM 2012), but selected different concentrations of certain parameters due to a lower percentage of coarse-grained sediment entering the EW from upstream. A discussion of how chemistry values were developed for the Green River is provided in Appendix B, Part 3B. Since the assembly of the Green River datasets used for the LDW FS, new data have been collected on the Green River (King County 2016; USGS 2016). Model input values have not been updated to include these new data for several reasons, as follows:

- The U.S. Geological Survey (USGS) is still reviewing and processing their data, which will be made available when their report is completed.
- Data from both USGS and King County studies are within the range of values previously used in the modeling, and therefore incorporating these new data would lead to results within the range presented in the sensitivity and bounding analysis in Section 2.3 of Appendix J.
- Any changes in results associated with incorporating the new data into additional modeling would have an equal bearing on all alternatives, and therefore would not affect the conclusions of this FS.

The new data are summarized in Appendix B, Part 3B.

Base case assumptions for LDW bed sediment and LDW lateral sediment sources were taken from values provided in the LDW FS (AECOM 2012). Bounding values were available for LDW lateral sources based on the LDW FS for the four human health risk driver COCs; however, these were not incorporated into the sensitivity analysis because the impact of LDW lateral sources on net upstream concentrations entering the EW are minor compared to the Green River concentrations (i.e., sensitivities are captured by the Green River bounding values). Chemistry assumptions for the LDW bed sediment were based on the baseline SWAC when available in the LDW FS (four human health risk drivers), and otherwise based on the baseline arithmetic average of LDW surface sediment samples (other five SMS contaminants). There was no bounding information in the LDW FS for LDW bed sediment site-wide; therefore, the base case for these input parameters were used for the bounding evaluation. Although the LDW is a cleanup site and will have lower concentrations in bedded sediment following cleanup, the current conditions were used for modeling because, like LDW laterals, the impact of LDW bed sediment on net upstream concentrations entering the EW are minor compared to the Green River concentrations. The Green River bounding evaluation captures any potential changes in the LDW bed sediment.

EW lateral sources were divided into two categories—SDs and CSOs—and separate chemistries were developed for each category as described in Appendix B, Part 4. Seeps and shoreline sheetflow are minor sources compared to lateral storm drains and CSOs in the EW, and were not included in the box model evaluation (see Section 2.11.3). These pathways will be assessed further during the design phase and through source control actions. Assumptions for both current and potential future chemistry conditions were developed for EW lateral sources (i.e., SDs and CSOs). Chemistry values for potential future conditions differed compared to current conditions for some COCs for SDs based on likely future source control efforts.[64] A base case and low and high bounding chemistry assumptions were developed for all EW lateral sources.

Values for chemistry assumptions for all incoming solids used for the box model evaluation are provided in Table 5-3.

Table 5-3
Chemistry Assumptions for Upstream and East Waterway Lateral Source Solids for the Site Performance Over Time Evaluation

Inputs	COC[1]			
	Arsenic (mg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Total PCBs (µg/kg dw)[2]	Dioxin/Furan TEQ (ng TEQ/kg dw)
Current Conditions				
EW CSOs[3] - Base	5	680	260	16
EW CSOs[3] - Low	6	430	240	7.6
EW CSOs[3] - High	9	1500	630	37
EW SDs[3] - Base	10	1300	250	27
EW SDs[3] - Low	9	480	55	12
EW SDs[3] - High	20	1900	450	53
LDW Laterals[4]	13	1400	300	20
LDW Bed[4]	15	380	340	26
Green River[5] - Base	9	135	42	6
Green River[5] - Low	7	40	5	2
Green River[5] - High	10	270	80	8
Future Source Control Conditions (EW Laterals)[6]				

[64] No changes were assumed for future conditions for CSO chemistry; however, changes were assumed for solids input due to CSO control plans (see Appendix B, Part 5 for details).

Table 5-3
Chemistry Assumptions for Upstream and East Waterway Lateral Source Solids for the Site Performance Over Time Evaluation

Inputs	COC[1]			
	Arsenic (mg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Total PCBs (µg/kg dw)[2]	Dioxin/Furan TEQ (ng TEQ/kg dw)
EW CSOs[3] - Base	5	680	260	16
EW CSOs[3] - Low	6	430	240	7.6
EW CSOs[3] - High	9	1500	630	37
EW SDs[3] - Base	10	**950**	**190**	**22**
EW SDs[3] - Low	9	480	55	12
EW SDs[3] - High	20	1900	450	**45**
LDW Laterals[4]	13	1400	300	20
LDW Bed[4]	15	380	340	26
Green River[5] - Base	9	135	42	6
Green River[5] - Low	7	40	5	2
Green River[5] - High	10	270	80	8

Notes:
1. Long-term effectiveness evaluation conducted only for the four human health risk driver COCs.
2. For reference, a total PCBs concentration of 192 µg/kg dw is equivalent to 12 mg/kg OC based on average TOC of 1.6% in EW surface sediments.
3. Methodology for determining values for EW CSOs and SDs provided in Appendix B, Part 4.
4. Values for LDW Bed and Laterals are taken from the LDW FS (AECOM 2012).
5. Methodology for determining values for the Green River provided in Section 5.3.1 and Appendix B, Part 3B.
6. Values are the same as current conditions (grey text) except where noted (**bold black text**).

µg/kg – micrograms per kilogram
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
EW – East Waterway
FS – Feasibility Study
LDW – Lower Duwamish Waterway
mg/kg – milligrams per kilogram
ng – nanograms
PCB – polychlorinated biphenyl
SD – storm drain
TEQ – toxic equivalent
TOC – total organic carbon

5.3.2 Incoming Solids Concentrations

Incoming solids concentrations were calculated for the four human health risk driver COCs using chemistry assumptions provided in Table 5-3 and estimates of annual deposition (mass) from upstream and EW lateral sources. Solids deposited in the EW from these sources were estimated as described below, and are summarized in Table 5-4. Sources of solids to the EW included in the incoming solids concentration calculations are upstream sources (Green River, LDW bed sediment, and LDW lateral inputs) and EW lateral inputs (SDs and CSOs). Deposition from these solids sources is assumed to be evenly distributed throughout the EW for the calculations.

An average net sedimentation rate for the EW was estimated using measured rates from geochronological cores as explained in Section 5.1.2. For evaluation purposes, this average net sedimentation rate was assumed to be consistent throughout the EW (the same rate applied everywhere); approximately 1.2 cm/yr.[65] Using the net sedimentation rate and an assumed density of the deposited sediment (taken from site-specific SEDflume core data), the total volume of deposited solids in the EW (on an annual basis) can be estimated. The impacts of this assumption on the predicted SWAC values were evaluated as part of a sensitivity evaluation that is discussed in detail in Appendix J.

This total volume of deposition was partitioned into contributions from the Green River, LDW bed sediment and lateral sources, and EW lateral inputs. Table 5-4 illustrates how this partitioning is done for current and future conditions, and the steps taken for current conditions are described below:

[65] The impacts of uncertainty in assumption of assumed net sedimentation rate on the results of the evaluation are discussed in Appendix J.

Table 5-4
Calculation of Net Sedimentation Rates used for the Site Performance Over Time Evaluation

Model Run	EW Lateral Solids Deposited in EW (kg/yr)	EW Lateral Solids Deposited in EW (cm/yr)	Measured Average NSR (current conditions (cm/yr)	% of EW Lateral Solids Contributed to NSR (%)	Annual Deposition from All Upstream Sources (cm/yr)	Annual Deposition From Green River (99.21% of Total Upstream Sources) (cm/yr)	Annual Deposition from LDW Bed (0.55% of Total Upstream Sources) (cm/yr)	Annual Deposition from LDW Laterals (0.24% of Total Upstream Sources) (cm/yr)	Calculated Average NSR for EW (future conditions) (cm/yr)
Base Case, Current	84,630	0.009	1.2	0.8%	1.191	1.182	0.0066	0.0029	NA
Lower Bound, Current	45,475	0.005	1.2	0.4%	1.195	1.186	0.0066	0.0029	NA
Upper Bound, Current	114,117	0.012	1.2	1.0%	1.188	1.179	0.0065	0.0029	NA
Base Case, Future	49,527	0.005	NA	0.4%	1.191	1.182	0.0066	0.0029	1.196
Lower Bound, Future	21,578	0.002	NA	0.2%	1.195	1.186	0.0066	0.0029	1.197
Upper Bound, Future	80,760	0.008	NA	0.7%	1.188	1.179	0.0065	0.0029	1.196

Notes:
cm/yr – centimeters per year
EW – East Waterway
kg/yr – kilograms per year
LDW – Lower Duwamish Waterway
NA – not applicable
NSR – net sedimentation rate

- The total mass of solids (in kilograms per year [kg/yr]) deposited in the EW from EW lateral inputs for current conditions (SDs and CSOs) is calculated from PTM results by adding all of the deposition predicted by the model within the EW.
- Using an assumed density of solids (1.5 g/cm^3),[66] the total mass of solids deposited in the EW from EW lateral sources is transformed to cm/yr.
- The calculated deposition rate for EW lateral inputs is subtracted from the total assumed net sedimentation rate for the EW determined from geochronology cores (1.2 cm/yr, see Section 5.1.2).
- The difference is assumed to represent the upstream solids contribution to the EW on an annual basis. The contribution from upstream solids sources to the total net sedimentation rate (as determined from geochronological cores) was evaluated in the absence of a full sediment transport model[67] to explicitly calculate the deposition rate from upstream sources alone.
- The upstream solids load consists of three sources: the Green River, LDW bed sediment, and LDW lateral inputs. The upstream deposition rate is divided between these three sources using solids loading to the EW predicted by the LDW sediment transport model (as described in the LDW FS; AECOM 2012).
- Different chemistry assumptions (see Table 5-3) are applied to each solids source as a post-processing step.

Solids loading to the EW were estimated for two conditions: current and future, where future conditions represent likely future source control actions applied to EW lateral sources (SDs and CSOs). These source control actions result in a reduction in the solids deposition in the EW from some EW lateral inputs and changes to chemistry in some SD solids. The solids contribution from upstream sources for future conditions is assumed to remain the same as current conditions. Overall, this assumption will result in a slightly lower total net sedimentation rate for future conditions in the EW than current conditions (as shown in Table 5-5). Current conditions solids loading will be applied to SWAC calculations for

[66] Representative density of deposited sediment in the EW taken from SEDflume data (collected by Sea Engineering, Inc. as part of the STER; Anchor QEA and Coast & Harbor Engineering 2012).

[67] A full sediment transport model was not conducted as part of the EW FS because EW sediment transport processes are highly impacted by vessel operations, which resuspend bed sediments due to propwash.

years 1 through 10 post-construction, and potential future conditions solids loading will be applied to the SWAC calculations for years 11 through 30. This timeframe assumes that the likely future source control actions that affect solids loading from EW lateral sources will be in place at the time. This time marker is just an assumption for EW modeling; changes for EW lateral sources may occur before or after this time marker.

Incoming solids concentrations calculated for the four COCs (using chemistry assumptions provided in Table 5-3 and partitioning among sources in Table 5-4) are provided in Table 5-5.

5.3.3 Sediment Bed Mixing Assumptions

Vertical mixing assumptions used in the box model evaluation were developed based on predicted maximum scour depths in the EW. Maximum predicted scour depths in the EW are discussed in Section 5.1.5 and are provided in Figure 5-2 and Table 5-2. Vertical mixing assumptions were developed to produce conservatively high estimates of surface concentrations in most situations by setting mixing depth assumptions to a value equal to or less than predicted scour depths in each operational area. This increases the impact of dredge residuals on the average concentration of the sediments once they are mixed by reducing the mixed volume of cleaner sediments underlying the dredge residuals that are mixed. Vertical mixing assumptions for the box model evaluation are shown in Figure 5-3. Intertidal areas that are not subject to propwash have a maximum vertical mixing depth of 10 cm, which represents the typical bioturbation mixing depth in the EW. Concentrations of underpier sediments were calculated assuming that the total sediment volume located in underpier areas are fully mixed, rather than by a set vertical depth.

The spatial extent of the EW surface sediments that is mixed due to vessel operations in the EW is variable from year to year, and therefore difficult to predict with precision. However, based on understanding of vessel operations and evaluation of geochronology cores in the EW, an estimate of the portion of the EW subject to vertical mixing due to propwash was made for the FS. The box model evaluation included mixing due to propwash by defining the percent of the EW open-water surface area that is predicted to be vertically mixed (bed sediments) over the 5-year temporal increment used in the box model evaluation. The

Table 5-5
Incoming Solids Concentrations

Deposited Solids[1]	% of total[2]	**Upstream**			**EW Laterals**		**Total**
		LDW Lateral 0.24%	**LDW Bed** 0.55%	**Green** 98.4% - 99.05%	**EW SDs** 0.16% - 0.66%	**EW CSOs** 0.01% - 0.20%	100%
COC-Time	**Scenario**	**Chemistry Assumptions**					**Incoming**[6,7] **Concentration**
		LDW Lateral[3]	**LDW Bed**[3]	**Green River**[4]	**EW SDs**[5]	**EW CSOs**[6]	
PCB-*Current* (µg/kg dw)	Base Case	300	350	42	250	260	45.7
	Low Bounding			5	55	240	8.0
	High Bounding			80	450	630	85.6
PCB-*Future* (µg/kg dw)	Base Case			42	190	260	44.9
	Low Bounding			5	55	240	7.7
	High Bounding			80	450	630	84.5
cPAHs-*Current* (µg TEQ/kg dw)	Base Case	1,400	390	135	1300	680	146
	Low Bounding			40	480	430	47
	High Bounding			270	1900	1500	287
cPAHs-*Future* (µg TEQ/kg dw)	Base Case			135	950	680	142
	Low Bounding			40	480	430	46
	High Bounding			270	1900	1500	283
Arsenic-*Current* (mg/kg dw)	Base Case	13	16	9	10	5	9.05
	Low Bounding			7	9	6	7.07
	High Bounding			10	20	9	10.10
Arsenic-*Future* (mg/kg dw)	Base Case			9	10	5	9.05
	Low Bounding			7	9	6	7.07
	High Bounding			10	20	9	10.09

Table 5-5
Incoming Solids Concentrations

<table>
<tr><th rowspan="3">Deposited Solids[1]</th><th rowspan="3">% of total[2]</th><th colspan="3">Upstream</th><th colspan="2">EW Laterals</th><th>Total</th></tr>
<tr><th>LDW Lateral</th><th>LDW Bed</th><th>Green</th><th>EW SDs</th><th>EW CSOs</th><th></th></tr>
<tr><td>0.24%</td><td>0.55%</td><td>98.4% - 99.05%</td><td>0.16% - 0.66%</td><td>0.01% - 0.20%</td><td>100%</td></tr>
<tr><th rowspan="2">COC-Time</th><th rowspan="2">Scenario</th><th colspan="5">Chemistry Assumptions</th><th rowspan="2">Incoming[6,7] Concentration</th></tr>
<tr><th>LDW Lateral[3]</th><th>LDW Bed[3]</th><th>Green River[4]</th><th>EW SDs[5]</th><th>EW CSOs[6]</th></tr>
<tr><td rowspan="3">Dioxin/Furan-
Current
(ng TEQ/kg dw)</td><td>Base Case</td><td rowspan="6">20</td><td rowspan="6">26</td><td>6</td><td>27</td><td>16</td><td>6.3</td></tr>
<tr><td>Low Bounding</td><td>2</td><td>12</td><td>7.6</td><td>2.2</td></tr>
<tr><td>High Bounding</td><td>8</td><td>53</td><td>37</td><td>8.5</td></tr>
<tr><td rowspan="3">Dioxin/Furan-
Future
(ng TEQ/kg dw)</td><td>Base Case</td><td>6</td><td>22</td><td>16</td><td>6.2</td></tr>
<tr><td>Low Bounding</td><td>2</td><td>12</td><td>7.6</td><td>2.2</td></tr>
<tr><td>High Bounding</td><td>8</td><td>45</td><td>37</td><td>8.3</td></tr>
</table>

Notes:
1. Methodology for determining volumes for deposited solids discussed in Sections 5.1.1 through 5.1.3.
2. See Table 5 in Appendix B, Part 1 for EW solids loads for all scenarios (base, low, and high for current and future conditions).
3. Values for LDW Bed and Laterals are taken from the LDW FS (AECOM 2012).
4. Methodology for determining values for the Green River provided in Section 5.3.1 and Appendix B, Part 3.
5. Methodology for determining values for EW CSOs and SDs provided in Appendix B, Part 4.
6. Incoming concentrations are calculated as a weighted average by mass for listed incoming sediment sources.

µg/kg – micrograms per kilogram
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
EW – East Waterway
FS – feasibility study
LDW – Lower Duwamish Waterway
mg/kg – milligrams per kilogram
ng – nanograms
PCB – polychlorinated biphenyl
SD – storm drain
TEQ – toxic equivalent

percent of the EW surface area that was allowed to mix over the 5-year time period was varied as part of the sensitivity analysis in Section 2.4 of Appendix J.

The estimate for approximate percent of the EW area that is subject to frequent propwash mixing was based on the review of the geochronology cores and the assigned net sedimentation rates by vessel operational area shown in Figure 5-1 and Table 5-1. Vessel operational areas were determined to be mixed if one of the following were true (based on Table 5-1):

- Area had an unrecovered core
- Area had a low-correlation Pb-210 core
- Area had a core with no Cs-137 peak
- Area was assigned a 0.5 or 0 cm/yr net sedimentation rate

These criteria were assumed to be indicative of mixing processes occurring in the area. The sum of vessel operational areas that met one of the above criteria represent approximately 50% of the EW. This is an empirical approximation of a physical process that is variable over the EW area and from year to year, but is considered a reasonable estimate for the purpose of comparing relative performance of proposed remedial alternatives over time. As mentioned above, the impact of the assumptions on results of the box model evaluation were determined through a sensitivity analysis described in Section 2.4 of Appendix J.

5.3.4 Exchange of Open-water and Underpier Sediments

Vessel scour by propwash in open-water and underpier areas results in exchange of sediments between those two areas due to resuspension of sediments by propwash into the water column, subsequent transport by tidal and river currents, and deposition of the resuspended material. In order to account for this physical mechanism in the box model evaluation, a mechanism for exchange of sediments between the open-water and underpier areas was included in the model calculations. This exchange was parameterized as an exchange of an equal volume of material between open-water and underpier areas over the same timeframe as vertical mixing (5 years, see Section 5.3.3).

The volume of material exchanged was assumed to be a percent of the total underpier sediment volume;[68] and was estimated based on the length of the pier face within EW that is adjacent to a vessel operational area predicted to have large propwash scour depths (see Figure 5-2). This impacted pierface length is approximately 25% of the total pierface length within the EW. Therefore, 25% of the total volume of the underpier sediments was assumed to mix with open-water areas every 5 years. As with the percent of the EW surface area that is mixed, this is an empirical approximation of a physical process that is spatially and temporally variable over the EW, but is considered a reasonable estimate for the purpose of comparing relative performance of proposed remedial alternatives over time. The impact of the assumed value of exchange on results of the box model evaluation were determined through a sensitivity analysis described in Section 2.3.2 of Appendix J.

5.3.5 Percent Reduction in Bioavailability of Hydrophobic Organic Contaminants Due to In Situ Treatment

In order to evaluate the effect of in situ treatment placement (i.e., activated carbon [AC]), the percent reduction in bioavailability of hydrophobic organic contaminants (i.e., total PCBs, cPAHs, and dioxins/furans) due to in situ treatment was estimated. This parameter applies only to remedial alternatives that proposed in situ treatment in underpier areas. The model input values for bioavailability were determined through review of literature and pilot study results in consideration of effectiveness and stability of AC over time (see Section 7.2.7.1.1 of the FS). The best estimate used in the box model evaluation is 70% reduction in contaminant bioavailability from in situ treatment. This value is based on laboratory and field studies in stable sediment that have consistently shown typical bioavailability reductions of 70% to 99% (see Section 7.2.7.1). The 70% biolavailability reduction used for the box model was selected from the low end of the range to account for dilution of AC during mixing and exchange of underpier sediment. The effects of the estimate of reduction in bioavailability on site-wide SWACs were determined through a sensitivity analysis described in Section 2.4 of Appendix J.

[68] The typical thickness of underpier sediments in the EW is approximately 2 feet (see Section 2.6) based on probing data, which equates to approximately 53,000 cubic yards of underpier sediments (see Section 2.2.2 of Appendix F).

5.3.6 Site-wide SWAC

A box model evaluation was used to predict the EW site-wide SWAC over time (years 0 through 40 following construction) for the four human health risk driver COCs (total PCBs, arsenic, cPAHs, and dioxins/furans) for each remedial alternative based on anticipated solids deposition and vertical mixing in the EW. For FS purposes, SWACs are used to estimate exposure point concentrations to assess risk to human or ecological receptors and for estimating the effectiveness of the alternatives at reducing that risk. Only these four risk drivers were analyzed in this way because their compliance is measured as a site-wide average concentration (see Table 4-3). These results were used to compare the site performance over time of the proposed remedial alternatives.

The calculations of the SWAC for the four human health risk driver COCs include the following factors:

1. Incoming solids inputs to the EW
2. Remedial technology for each alternative applied to each portion of the remediation area:
    a. Surface chemistry concentrations post-remedial action at Time 0 in remediated and unremediated areas
    b. Dredge residuals volume and chemistry (at Time 0)
    c. Chemistry associated with deeper sediments subject to mixing
3. Physical mixing assumptions based on the propwash evaluation (see Section 5.3.3)

The box model evaluation calculates the site-wide SWAC at various time intervals by dividing the EW into sub-areas based on remedial technology and mixing depth. SWAC values are calculated for each sub-area and are then averaged (by area) to calculate the site-wide SWAC. This approach accounts for variation across the site based on remedial technology and mixing depth. The site-wide SWAC values are calculated every 5 years; therefore, SWAC values will be estimated for years 0, 5, 10, 15, 20, 25, 30, 35, and 40 post-construction.

The specific steps used to calculate the site-wide SWAC are summarized in this section. A more detailed discussion, including the mathematical basis for the calculations and uncertainty discussion of the site-wide SWAC, is provided in Appendix J.

Step 1: Parse the EW into Sub-Areas

The EW was divided up into sub-areas based on location and extent of proposed remedial technology (as defined by each proposed alternative) and mixing depth assumptions. Figure 5-4 provides a schematic illustrating how the sub-areas were developed.

First, the EW surface area was divided into sub-areas based on location and spatial extent of remedial technologies proposed for each developed alternative (second panel from top in Figure 5-4). These sub-areas were further sub-divided based on the assumed depth of the mixing zone[69] (third panel from top in Figure 5-4). This division results in a series of areas within the EW that have both the same remedy and mixing depth (bottom panel in Figure 5-4).

The surface area for sub-areas that have the same remedy and mixing zone will be added together to create a tabular summary of each alternative discussed in Section 8. These tabular summaries are provided in Appendix J.

Step 2: Define Bed Mixing Models for Each Remedial Technology/Mixing Zone Combination

A bed mixing model was developed for each remedial technology and potential mixing depth (sub-areas developed in Step 1). The bed mixing model defines the vertical layers of sediment at Time 0 (post-construction) for each area considering remedial technology and the vertical extent of the assumed mixing depth. The three vertical sediment layers defined in the bed mixing model include RMC, dredge residuals, and sediment bed remaining after remedial action. A schematic example of the bed mixing model at Time 0 is shown in Figure 5-5 for remediated areas (top panel) and non-remediated areas (bottom panel). Detailed figures of bed mixing models for each proposed remedy and mixing depth combination are provided in Appendix J.

Step 3: Calculate Site-wide SWAC

The upstream and lateral solids loads and chemistry for current and future conditions (Section 5.3.2), table of sub-areas by remedy/mixing zone (Step 1) and the associated bed

[69] Mixing depth assumptions are shown in Figure 5-3, and discussed in Section 5.3.3.

mixing model (Step 2) are used to calculate the site-wide SWAC every 5 years for years 0 through 40 post-construction.

Each remedy/mixing zone sub-area developed in Step 1 is assumed to fully mix during each 5-year time period based on the bed mixing model and mixing depth defined for that sub-area. After mixing occurs, a surface sediment (top 10 cm) concentration is calculated for each remedy/mixing zone sub-area over the defined mixing depth. The site-wide SWAC for the EW is then calculated by averaging these concentration values for each remedy/mixing zone sub-area using Equation 5-1:

$$\frac{\sum_{i=1}^{n} A_i \times C_i}{\sum_{i=1}^{n} A_i} = \text{SWAC (site-wide)} \qquad (5\text{-}1)$$

where:

n	=	Total number of sub-areas
A_i	=	Area of sub-area
C_i	=	Concentration of surface sediments (averaged over the mixing depth) for each sub-area

A detailed description, including mathematical basis, of the site-wide SWAC calculations is provided in Section 2 of Appendix J.

5.3.7 Area-specific SWAC

In addition to the site-wide SWAC; the box model evaluation was used to estimate SWAC values for specific areas to inform the evaluation of alternatives where MNR may be selected as the remedial technology (e.g., underpier areas) and to assess compliance with RAO 2 in clamming areas (see Table 4-3). These calculations were done using the same Steps 1 through 3 discussed in Section 5.3.6, where the total area considered is a specific subsection of the EW site. A detailed description, including mathematical basis, of the site-specific SWAC calculations is provided in Appendix J.

5.3.8 Sensitivity and Bounding Evaluations

To account for variability and uncertainty in the physical processes and sediment/solids chemistry values used in the box model evaluation, and determine their impacts to the evaluation of site performance over time, two analyses were completed as part of the FS: sensitivity and bounding. The purpose of the sensitivity analysis was to evaluate the relative impact of each parameter to the site-wide SWAC value or surface concentrations over time predicted by the evaluation. The bounding analysis was based on the results of the sensitivity evaluation, and was used to bound the range of potential SWAC values based on combinations of parameters that could have the most effect on the predicted SWAC values. These analyses were done using information specific to a proposed remedial alternative to ensure that the response of the SWAC calculations to changes in parameters reflects the complexity of the proposed alternatives; remedial Alternatives 1A(12) and 2B(12) were used (see Sections 8.2.5 and 8.2.8 and Figures 8-2 and 8-5). These alternatives were chosen for the sensitivity analysis because of their differences: Alternative 1A(12) has less removal than Alternative 2B(12) in open-water areas and has MNR proposed in underpier areas, whereas Alternative 2B(12) proposes in situ treatment in underpier areas. Therefore, the effect of the input parameters on the remedial technologies could be explored. See Sections 7 and 8 for a description of the remedial technologies and the alternatives, respectively. The details and results of these evaluations are discussed in Appendix J, including the uncertainty of the estimated SWAC values based on selection of specific calculation parameters.

5.4 Recontamination Potential Evaluation

The potential for the site to recontaminate following remedial actions has also been evaluated as part of the FS. The purpose of the recontamination potential evaluation is to determine if there are discrete areas within the EW where recontamination may be of concern based on deposition from upstream and EW lateral solids. Portions of the EW predicted to exceed the RALs were used as a metric to identify areas where potential recontamination could occur to inform where post-construction monitoring may be needed.

The evaluation of recontamination potential is challenging in the EW due to the influence of anthropogenic activity, such as propwash, which can resuspend recently deposited finer sediments and/or mix them into the underlying sediments. The impacts of anthropogenic activity on the spatial distribution of EW lateral solids deposition was not taken into account with the PTM because of the difficulty in accurately quantifying the location, mass, and frequency of solids resuspended by vessel activity. Therefore, the recontamination evaluation focused on identifying areas of concern using RALs as metrics without attempting to quantify surface concentrations in the long term with certainty.

The recontamination potential evaluation was conducted using the results of numerical modeling (i.e., PTM) as input to a GIS-based mathematical model to identify specific areas within the EW that may have the potential to recontaminate in the future. These areas were further evaluated to determine if predictions are reasonable, whether areas of recontamination have a significant adverse impact on maintaining RAOs, and to help inform and focus long-term monitoring efforts following completion of the remedial actions. This evaluation is referred to as the grid model evaluation.

The initial deposition quantities and patterns of EW lateral solids sources (i.e., CSOs and SDs) within the EW area were determined through use of a PTM. Deposition based on current solids loading was provided in Section 7 of the STER (Anchor QEA and Coast & Harbor Engineering 2012). Additional modeling using the PTM was conducted as part of the FS to evaluate initial deposition of EW lateral inputs once likely future source control measures are employed. Appendix B, Part 1 provides a detailed description of the additional modeling using the PTM for future conditions. An overview of solids input and deposition in the EW is provided in Section 5.1.

For both the current and future PTM outputs, different chemical concentrations were applied to the distribution of solids predicted to be deposited in each PTM grid cell from each lateral solids load and upstream sources (constant throughout the EW) to calculate surface sediment concentrations in the upper 10 cm. The results of both the current and future model outputs were used to identify discrete areas within the EW where recontamination potential could be a concern. The sections below provide an overview of the physical process and chemistry assumptions used in the recontamination potential evaluation, and the methodology used for evaluation.

5.4.1 Review of PTM

The output and post-processing for the PTM is described in detail in Section 7 of the STER (Anchor QEA and Coast & Harbor Engineering 2012) and additional, potential future, conditions were run with the PTM and described in detail in Appendix B, Part 1. However, for the purposes of the FS, a brief review of the output of the PTM is provided to assist with the methodology discussion for the recontamination potential evaluation.

The raw output of the PTM includes particle locations within the EW that represent where solids from various EW lateral sources have deposited in the EW. This is an initial deposition and does not including resuspension and lateral movement after deposition. The locations of all the deposited particles (from all EW lateral solids sources) were extracted from the raw PTM output file and imported into ArcGIS. The points were then post-processed to create a raster representation of mass accumulation in the EW with a 50-foot by 50-foot resolution.[70] Mass accumulation within each 50-foot by 50-foot cell in the raster was calculated by adding all of the particles that had been deposited within that area. This cell size was chosen to provide an appropriate level of resolution for predicting solids deposition patterns within the EW and to assess the recontamination potential within the EW.[71] Figures showing these initial deposition patterns and quantities in the EW for all EW lateral sources are provided in Appendix B, Part 1.

5.4.2 Chemistry Assumptions

Nine COCs were selected for the recontamination potential evaluation. Seven of these are key benthic risk driver COCs (total PCBs, arsenic, mercury, total high-molecular-weight polycyclic aromatic hydrocarbon [HPAHs], total low-molecular-weight polycyclic aromatic hydrocarbons [LPAHs], BEHP, and 1,4-dichlorobenzene), which together serve as a surrogate for the 29 SMS contaminants identified as benthic invertebrate community COCs in the ERA (Windward 2012a). Note that total PCBs and arsenic are also human health risk

[70] Each particle represents 0.5 kg of sediment; see Section 7.3.3 of the STER (Anchor QEA and Coast & Harbor Engineering 2012) for more information.

[71] An evaluation of the influence of cell size on concentrations and deposition patterns predicted by the PTM can be found in Section 7.3.5 of the STER.

drivers. The other two COCs for the recontamination potential evaluation are the remaining human health risk drivers (cPAHs and dioxins/furans).

Chemistry assumptions for upstream sources for the recontamination potential evaluation were developed using the same methodology as used for the box model (see Section 5.3.1). However, chemistry assumptions for EW lateral sources were refined in the PTM analysis compared to box model. The recontamination potential evaluation assigns chemistry based on consideration of individual or similar SD and CSO basin characteristics that could result in more basin-specific chemistry assignments. This is because the PTM is used to evaluate location-specific conditions; whereas the box model, which assigned one chemistry to SDs and one to CSOs, evaluates a site-wide average concentration rather than location-specific conditions. Since the recontamination evaluation calculates surface concentrations based on a model cell-by-cell basis based on initial deposition patterns predicted by the PTM output, it is necessary to break down EW lateral sources into finer resolution for chemistry assumptions. Chemistry assumptions for the recontamination potential evaluation are assigned for current and future source control conditions based on the following six categories:

- Hinds CSO
- Lander CSO
- Hanford #2 CSO
- Nearshore SDs (Port of Seattle, City of Seattle, and private)
- S Lander St SD
- All non-nearshore SDs (e.g., S Hinds St SD, USCG SD, etc.)

Decisions on these refinements considered the current source control chemistry data, number of source control samples, similarities of land uses of the basins, and future source control actions. Appendix B, Part 4 provides a detailed discussion of how chemistry assumptions for EW lateral sources were developed. Tables 5-6 and 5-7 provide chemistry assumptions used for the recontamination potential evaluation for upstream and EW lateral sources for current and future (source control) conditions, respectively.

Table 5-6

Chemistry Assumptions for Upstream and East Waterway Lateral Source Solids for Recontamination Potential Evaluation (Current Conditions)

	COC								
Inputs	**Arsenic (mg/kg dw)**	**Mercury (mg/kg dw)**	**Total HPAHs (µg/kg dw)**	**Total LPAHs (µg/kg dw)**	**Total cPAHs (µg TEQ/kg dw)**	**BEHP (µg/kg dw)**	**1,4-DCB (µg/kg dw)**	**Total PCBs (µg/kg dw)**	**Dioxin/Furan TEQ (ng TEQ/kg dw)**
Hinds CSO									
mean[1]	5	1.71	4,000	870	680	6,700	820	260	16
median[2]	6	0.36	2,900	640	430	3,000	260	240	7.6
90th percentile[3]	9	2.57	10,000	1,900	1,500	23,000	2,000	630	37
Lander CSO									
mean[1]	2	0.21	1,800	280	250	1,000	320	11	1.8
median[2]	2	0.25	2,200	220	300	800	230	11	1.8
90th percentile[3]	2	0.26	2,700	500	380	1,700	560	18	2.6
Hanford #2 CSO									
mean[1]	6	2.00	3,900	880	670	7,700	990	270	30
median[2]	6	0.72	3,100	670	540	3,300	320	250	30
90th percentile[3]	9	2.94	6,200	1,600	930	27,000	2,300	510	44
Nearshore SDs[4]									
mean[1]	10	0.09	5,500	1,000	820	8,300	75	160	15
median[2]	10	0.08	4,400	740	550	6,200	17	39	7.9
90th percentile[3]	15	0.14	14,000	1,900	2,100	19,000	180	440	32
S Lander St SD									
mean[1]	9	0.15	14,000	2,600	2,100	12,000	110	120	68
median[2]	10	0.13	5,500	810	670	9,300	90	53	68
90th percentile[3]	20	0.29	17,000	3,400	2,400	21,000	200	280	93
All Non-nearshore SDs[5]									
mean[1]	10	0.19	10,000	2,000	1,400	19,000	140	290	68
median[2]	7	0.12	4,000	680	450	9,400	90	58	68
90th percentile[3]	20	0.32	11,000	3,400	1,700	24,000	280	460	93
LDW Laterals[6]									
base	13	0.14	3,900	880	1,400	15,475	990	300	20
LDW Bed[7]									
base	16	0.53	3,800	700	390	590	23	350	26
Green River									
base	9	0.10	1,300	130	135	120	1.20	42	6
low bounding	7	0.06	160	17	40	75	0.84	5	2
high bounding	10	0.20	1,900	230	270	210	1.30	80	8

Notes:
1. Mean chemistry values are used for Base Case scenarios.
2. Median chemistry values are used for Low Bounding Case scenarios.
3. 90th percentile chemistry values are used for High Bounding Case scenarios.
4. Nearshore SDs include SW Florida St SD (B-21), B-25, all Port SDs, and all private SDs along the waterfront (A-6, B-40, B-41, B-42, B-43).
5. Non-nearshore SDs include S Hinds St SD, SW Spokane St EOF/SD (B-5), SW Spokane St SD (B-4), S Spokane St SD (B-36), and all bridges (BR-2, BR-4, BR-34, BR-39).
6. Values for LDW Laterals are taken from the LDW FS (AECOM 2012) when available.
7. Values for LDW Bed are based on the baseline SWAC when available in the LDW FS (AECOM 2012) (for the four human health risk driver COCs), and are otherwise based on the baseline average of surface sediment samples (for other SMS contaminants).

µg/kg – micrograms per kilogram
1,4-DCB – 1,4-dichlorobenzene
BEHP – bis(2-ethylhexyl) phthalate
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
EOF – emergency overflow
FS – Feasibility Study
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LDW – Lower Duwamish Waterway
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
ng – nanograms
PCB – polychlorinated biphenyl
SD – storm drain
SMS – Washington State Sediment Management Standards
SWAC – spatially-weighted average concentration
TEQ – toxic equivalent

Table 5-7

Chemistry Assumptions for Upstream and East Waterway Lateral Source Solids for Recontamination Potential Evaluation (Future Conditions)

Inputs	COC								
	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	BEHP (µg/kg dw)	1,4-DCB (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxin/Furan TEQ (ng TEQ/kg dw)
Hinds CSO									
mean[1]	5	1.71	4,000	870	680	6,700	820	260	16
median[2]	6	0.36	2,900	640	430	3,000	260	240	7.6
90th percentile[3]	9	2.57	10,000	1,900	1,500	23,000	2,000	630	37
Lander CSO									
mean[1]	2	0.21	1,800	280	250	1,000	320	11	1.8
median[2]	2	0.25	2,200	220	300	800	230	11	1.8
90th percentile[3]	2	0.26	2,700	500	380	1,700	560	18	2.6
Hanford #2 CSO									
mean[1]	6	2.00	3,900	880	670	7,700	990	270	30
median[2]	6	0.72	3,100	670	540	3,300	320	250	30
90th percentile[3]	9	2.94	6,200	1,600	930	27,000	2,300	510	44
Nearshore SDs[4]									
mean[1]	10	0.09	5,500	1,000	820	8,300	75	160	15
median[2]	10	0.08	4,400	740	550	6,200	17	39	7.9
90th percentile[3]	15	0.14	14,000	1,900	2,100	19,000	180	440	32
S Lander St SD									
mean[1]	9	0.15	**8,600**	**1,600**	2,100	12,000	110	120	**22**
median[2]	10	0.13	5,500	810	670	9,300	90	53	**12**
90th percentile[3]	20	0.29	17,000	3,400	2,400	21,000	200	280	**37**
All Non-nearshore SDs[5]									
mean[1]	10	**0.16**	**6,800**	**1,600**	**930**	**14,000**	140	**200**	**22**
median[2]	7	0.12	4,000	680	450	9,400	90	58	**12**
90th percentile[3]	20	0.32	11,000	3,400	**1,600**	24,000	**260**	460	**37**
LDW Laterals[6]									
base	13	0.14	3,900	880	1,400	15,475	990	300	20
LDW Bed[7]									
base	16	**1**	3,800	700	390	590	23	350	26
Green River									
base	9	0.10	1,300	130	135	120	1.20	42	6
low bounding	7	0.06	160	17	40	75	0.84	5	2
high bounding	10	0.20	1,900	230	270	210	1.30	80	8

Notes:

1. Mean chemistry values are used for Base Case scenarios.
2. Median chemistry values are used for Low Bounding Case scenarios.
3. 90th percentile chemistry values are used for High Bounding Case scenarios.
4. Nearshore SDs include SW Florida St SD (B-21), B-25, all Port SDs, and all private SDs along the waterfront (A-6, B-40, B-41, B-42, B-43).
5. Non-nearshore SDs include S Hinds St SD, SW Spokane St EOF/SD (B-5), SW Spokane St SD (B-4), S Spokane St SD (B-36), and all bridges (BR-2, BR-4, BR-34, BR-39).
6. Values for LDW Laterals are taken from the LDW FS (AECOM 2012).
7. Values for LDW Bed are based on the baseline SWAC when available in the LDW FS (AECOM 2012) (for the four human health risk driver COCs), and are otherwise based on the baseline average of surface sediment samples (for other SMS contaminants).

Values are the same as current conditions shown in Table 5-6 (grey text) except where noted (**bold black text**).

µg/kg – micrograms per kilogram
1,4-DCB – 1,4-dichlorobenzene
BEHP – bis(2-ethylhexyl) phthalate
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
EOF – emergency overflow
FS – Feasibility Study
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LDW – Lower Duwamish Waterway
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
ng – nanograms
PCB – polychlorinated biphenyl
SD – storm drain
SMS – Washington State Sediment Management Standards
SWAC – spatially-weighted average concentration
TEQ – toxic equivalent

5.4.3 Contribution from Upstream Solids Sources

The average net sedimentation rate assumed for the EW for use in the box model evaluation (see Section 5.1.2), 1.2 cm/yr, was also applied to the entire EW to represent annual net deposition (for current conditions) due to all solids sources identified in Section 5.1.1.

The method used to estimate the contribution of upstream solids sources (for current conditions) to the average net sedimentation rate is different from what was used in the box model evaluation (see Table 5-4). Instead of using the entire EW surface area to estimate a deposition rate in cm/yr from upstream and EW lateral inputs, the smaller surface area where the PTM predicts deposition from EW lateral inputs was used (the shaded areas shown in Figures 7 through 12 in Appendix B, Part 1). This results in a slightly larger contribution from EW lateral inputs (in cm/yr over that smaller area) in those locations compared to how it was depicted in the box model evaluation, where deposition from EW lateral inputs were spread evenly throughout the entire EW area. The contribution from upstream sources for current conditions in those locations is calculated by subtracting the contribution from EW lateral sources from the assumed average net sedimentation rate measured by geochronological cores (1.6 cm/yr, see Section 5.1.2). These calculations are provided in Appendix J.

The solids contribution from upstream sources for future conditions is assumed to remain the same as current conditions (see Appendix J). This is because the majority of the upstream solids are from the Green River and there is no information available to suggest changes in the solids load from the Green River in the future. The contribution of EW lateral solids sources for likely future conditions were estimated using the updated PTM simulations with likely future source control measures applied to EW lateral solids loads. Annual deposition from EW laterals solids for future conditions is less than current conditions for some discharges due to proposed source control measures, which reduce the amount of sediment coming in from some lateral sources (see Appendix B, Part 1). Since the predicted contribution to total annual deposition in the EW from EW laterals for future conditions is decreased, and the upstream contribution is assumed to be the same as current conditions, predicted total deposition from all sources for future conditions is slightly less than current conditions.[72]

5.4.4 Vertical Mixing Assumptions

The vertical mixing assumptions used for the recontamination evaluation are constant throughout the EW and equal to a bioturbation depth of 10 cm (depth of the BAZ as determined in the EW SRI; Windward and Anchor QEA 2014). Vertical mixing due to propwash is not considered when evaluating recontamination potential. These assumptions result in conservatively high estimates of surface concentrations in areas where the deposition from EW lateral sources is predicted to be high.

5.4.5 Spatial Distribution of Surface Concentrations in the East Waterway

The results of the current and future conditions (after future source control is implemented) deposition from EW lateral sources (see Section 5.4.1), chemistry assumptions (Section 5.4.2), contribution of upstream sources to the EW (Section 5.4.3), and vertical mixing assumptions (Section 5.4.4), were used to determine if there are any discrete areas within the EW that have the potential to recontaminate following remediation.

This evaluation was accomplished by calculating surface concentrations within each 50-foot by 50-foot PTM grid cell (cell).[73] The information required in each cell is listed below:

- The underlying surface concentrations throughout the EW at Time 0 (post-construction) for each COC were assumed to be zero. This assumption was made to focus the evaluation on recontamination potential due to incoming solids.
- Initial deposition from EW lateral solids sources from PTM results (with and without future source control actions).

[72] Total predicted deposition from all sources for current conditions was taken from the assumed average net sedimentation rate for the EW measured by geochronological cores (see Section 5.1.2).

[73] Surface concentrations will be calculated using dry weight concentrations for all nine key risk driver COCs and will also be calculated as carbon-normalized concentrations for total PCB, HPAH, LPAH, 1,4-dichlorobenzene, and BEHP for comparison to benthic community PRGs.

- EW lateral solids chemical concentrations for nine key risk driver COCs (including both human health and ecological)[74] for existing and future conditions (Section 5.4.2 and Tables 5-6 and 5-7).
- Contribution of upstream sediment solids sources to assumed average total net sedimentation rate (see Section 5.4.3).
- Upstream solids chemical concentrations for the nine key risk driver COCs being evaluated (Tables 5-6 and 5-7).
- Mixing depths (set to 10 cm due to bioturbation for all cells).

Surface concentrations within each cell will be calculated in four steps described below:

1. The upstream contribution (in kg/yr) is a constant value for each cell and is set to a value estimated as described in Section 5.4.3. A chemical concentration (in mass per kg of solids) for the nine key risk driver COCs being evaluated are associated with the upstream contribution of solids in each cell (these values are the same for current and future conditions).
2. The underlying location specific surface sediment chemical concentrations in each cell were set to zero for all COCs and proposed alternatives (see Appendix J).
3. The PTM output (for both current and future/source control conditions) provides deposition (in kg/yr) of EW lateral solids sources in each cell. A chemical concentration (in mass per kg of solids) for the nine key risk driver COCs being evaluated are associated with the EW lateral solids in each cell (for both current and future/source control conditions, based on the six categories of EW lateral sources outlined in Section 5.4.2).
4. The depositional solids concentrations in each cell (due to upstream and EW lateral solids contributions) is mixed (based on the 10-cm bioturbation thickness) with the underlying sediment chemical concentrations to establish surface concentrations annually for years 1 to 30 post-construction.

[74] All nine risk driver COCs are evaluated for recontamination potential, but only those identified as risk driver COCs for the benthic community will be evaluated in the site performance over time evaluation; the box model evaluation is used for the site performance over time evaluation for the other RAOs (human health and other ecological receptors).

The output of the evaluation includes maps summarizing areas in the EW that exceeds RALs and CSLs for years 5, 10, 15, and 30 years post-construction. The resolution of the maps is the same as the predicted EW lateral deposition maps developed from the PTM results (see Figure 2-14), which is 50 feet by 50 feet. This information was used to evaluate localized recontamination potential for discrete areas in the EW.

5.4.6 Sensitivity Analyses

The sensitivity of predicted surface concentrations in each cell due to uncertainty in the model inputs (both solids load and assumed chemistry) was evaluated through development of upper and lower bound scenarios. These scenarios are a combination of a low- and high-level estimate of both solids input and chemistry assumptions. Low solids loads were paired with low chemistry assumptions, and likewise with mid- and high-level estimates for solids and chemistry to properly bound the results of the evaluation. The list of sensitivity and bounding scenarios and discussion of the analysis for the recontamination potential evaluation is provided and discussed in Appendix J. An uncertainty discussion for this evaluation is discussed in detail in Appendix J and summarized in Section 5.6.3 herein.

5.5 Point Mixing Model for Evaluation of RAO 3

The box model evaluation described above was used to estimate site-wide and area-specific SWACs for alternatives to assess compliance with RAOs 1, 2, and 4, which are evaluated based on area-average concentrations. RAO 3, however, is assessed based on individual point locations as opposed to area averages. Therefore, an additional calculation, referred to as the point mixing model evaluation, was conducted for seven key benthic risk drivers to predict compliance with RAO 3. These seven key benthic risk drivers serve as surrogates for the 29 SMS contaminants identified as benthic invertebrate community COCs in the ERA (Windward 2012a) and include total PCBs, arsenic, mercury, total HPAHs, total LPAHs, BEHP, and 1,4-dichlorobenzene. The point mixing model uses similar assumptions as the box model evaluation to predict surface sediment concentrations for years 0 through 40 post-construction for 18 point locations (baseline surface sediment stations) in proposed MNR areas that exceed the RAO 3 PRGs. This analysis was limited to these point locations because other locations are expected to meet RAO 3 PRGs following construction (either through active remediation, such as dredging, or because they are below RAO 3 PRGs currently). As discussed in Section 9, evaluation of RAO 3 is based on all sample locations (342) throughout the EW. This point mixing model is used to predict the outcome of 18 locations planned for MNR (in underpier and under bridge areas). All other locations are expected to meet RAO 3 PRGs following construction, either through active remediation because they are above RALs, or because they are below RAO 3 RALs/PRGs currently. This evaluation is also discussed in Section 9.2.2 of the FS.

This evaluation uses the similar methodology for calculating surface concentrations as the box model; however, instead of calculating area-wide average concentrations, concentrations are estimated at 18 discrete sample locations in underpier and under-bridge areas (Figure 5-6) where MNR is being proposed in select remedial alternatives. Assumptions for deposited solids and mixing used for this evaluation are summarized below:

- Year 0 surface chemistry at each of these points is based on baseline surface sediment concentrations (i.e., samples taken at these locations between 2001 and 2009).
- EW lateral solids deposition at each point predicted by the PTM results in the model cell that point falls within. Therefore, deposition from EW laterals sources varies across the 18 point locations.
- Upstream solids deposition rate is assumed to be constant across the EW; values are the same as those used for the recontamination potential evaluation (Appendix J).
- Chemistry assumptions for EW lateral and upstream sources are the same as those assumed for the recontamination evaluation (Tables 5-6 and 5-7).
- Mixing assumptions (depths and timeframes for mixing to occur) are the same as the box model evaluation (see Section 5.3.3).

Surface concentrations at each point were predicted for years 5 through 40 (at 5-year intervals), and results were compared to RALs and SMS marine benthic CSLs. The results of the evaluation are provided in Section 9. A detailed description of the calculations, including mathematical basis, is provided in Appendix J.

The sensitivity of predicted surface concentrations at each point to various parameter assumptions is discussed in Appendix J, but is assumed to be similar to the sensitivity of the surface concentrations (SWAC values) calculated in the box model evaluation.

5.6 Uncertainty Discussions

Uncertainty of input variables and calculation methodology for the evaluation of site performance over time (box model evaluation and point mixing model) and recontamination potential was assessed based on sensitivity and bounding evaluations, which are discussed in detail in Appendix J and summarized below. Overall, the predictive model performed as expected when varying input parameters, and the overall uncertainty of the model predictions is acceptable for use in comparison of alternatives within the framework of the FS.

5.6.1 Uncertainty Associated with Input Values

There are numerous uncertainties associated with methods used to determine input values for the predictive modeling analysis summarized in this section. These uncertainties are documented in detail in previous finalized documents. Uncertainty associated with the EW STE, such as measured values of net sedimentation rates from recovered geochronology core data collection and laboratory analyses, predicted initial deposition from EW lateral inputs by the PTM, and shear stresses calculated from vessel operations are discussed in detail in Sections 3.4, 6.3.1, and 7.3.7 in the STER (Anchor QEA and Coast & Harbor Engineering 2012). Discussions of uncertainties in chemistry assumptions used as input for the evaluations are discussed in Appendix B, Parts 3B and 4.

5.6.2 Box Model and Point Mixing Model Evaluation

Section 2.4 in Appendix J provides detail on the sensitivity and bounding analysis for the box model evaluation. Based on the results of the bounding analysis, site-wide SWAC values can vary up to +125% at year 10 and by up to +100% at year 30 due primarily to uncertainty in Green River inputs (solids loading and chemistry assumptions) and net sedimentation rates. When the Green River input and net sedimentation rates are held at the base case assumption, and the other variables (i.e. residuals thickness, percent exchange) are varied within their accepted high and low ranges, SWAC values can vary up to +50% at year 10 and by up to +20% at year 30.

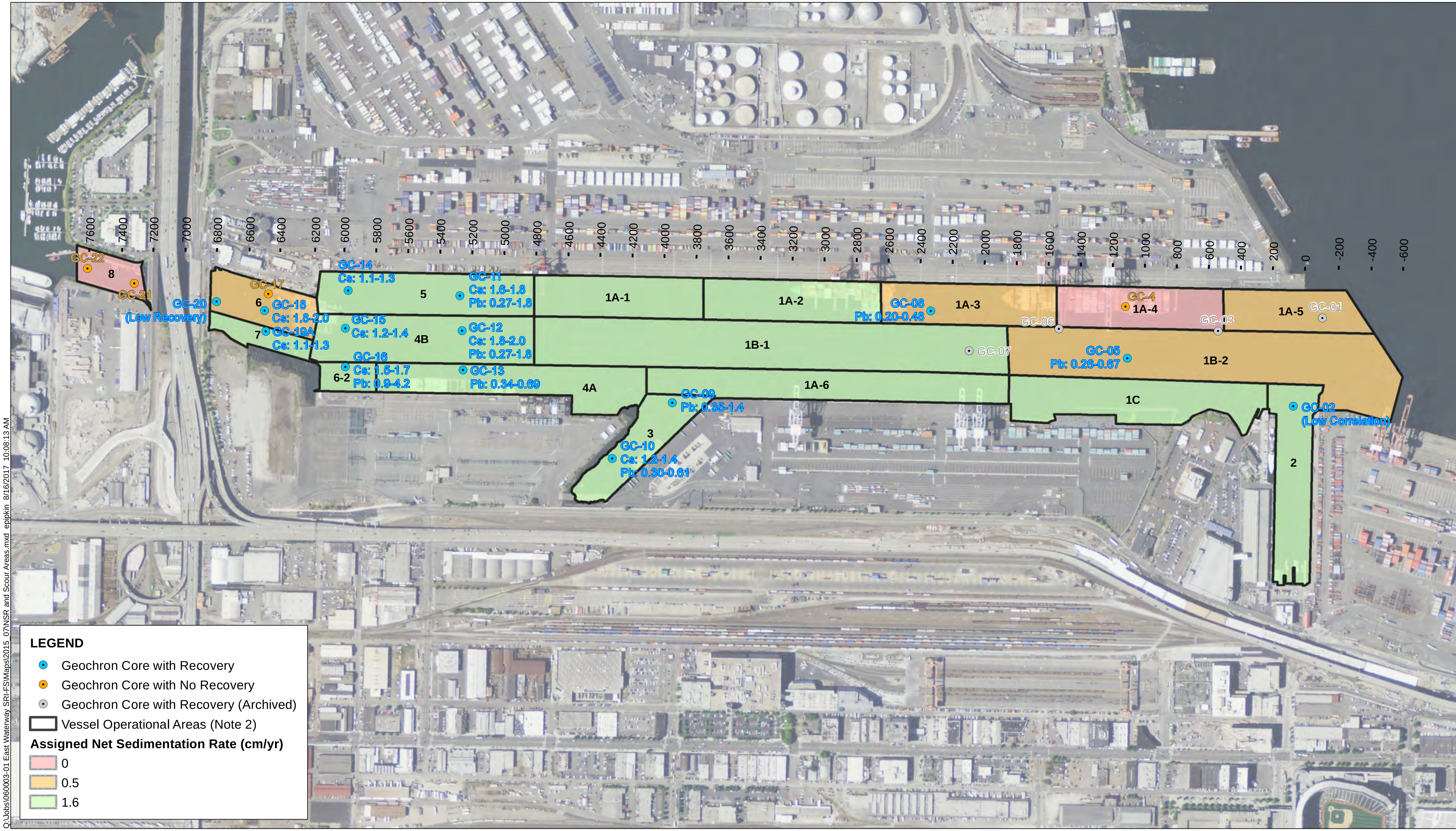
The sensitivity analysis was conducted for two proposed alternatives (Alternatives 1A(12) and 2B(12)[75]) to determine if the uncertainty in the predicted SWAC values is substantially different between alternatives. Detailed discussion of this analysis is located in Sections 2.4.2.1 and 2.4.2.2 of Appendix J. In summary, while the sensitivity of the predicted SWAC calculations to individual parameters differed somewhat between the two alternatives, the range in predicted SWAC values based on the full range of uncertainty in the input parameters was similar for both alternatives. Therefore, while the range of uncertainty in predicted SWAC values is broad based on the uncertainty in the input parameters for the analysis, the box model evaluation is appropriate for comparison of alternatives within the framework of the FS.

The point mixing model evaluation uses the same mathematical model as the box model evaluation. Uncertainties in the predicted surface concentrations for proposed MNR areas calculated with the point mixing model are, therefore, in line with the uncertainties provided for the box model evaluation described in the previous paragraph.

5.6.3 Recontamination Potential Evaluation

A bounding analysis was conducted to estimate uncertainty in predictions of recontamination potential (see Section 4.5 of Appendix J). The results of the bounding evaluation suggest that predictions of the areas of potential recontamination are reduced when inputs are reduced and increase when inputs are increased, as anticipated. However, for all bounding scenarios, areas of concern represent a small portion of the EW area and do not extend far from source outfalls.

[75] See Sections 8.2.5 and 8.2.8 and Figures 8-2 and 8-5 for a detailed description of Alternatives 1A(12) and 2B(12).

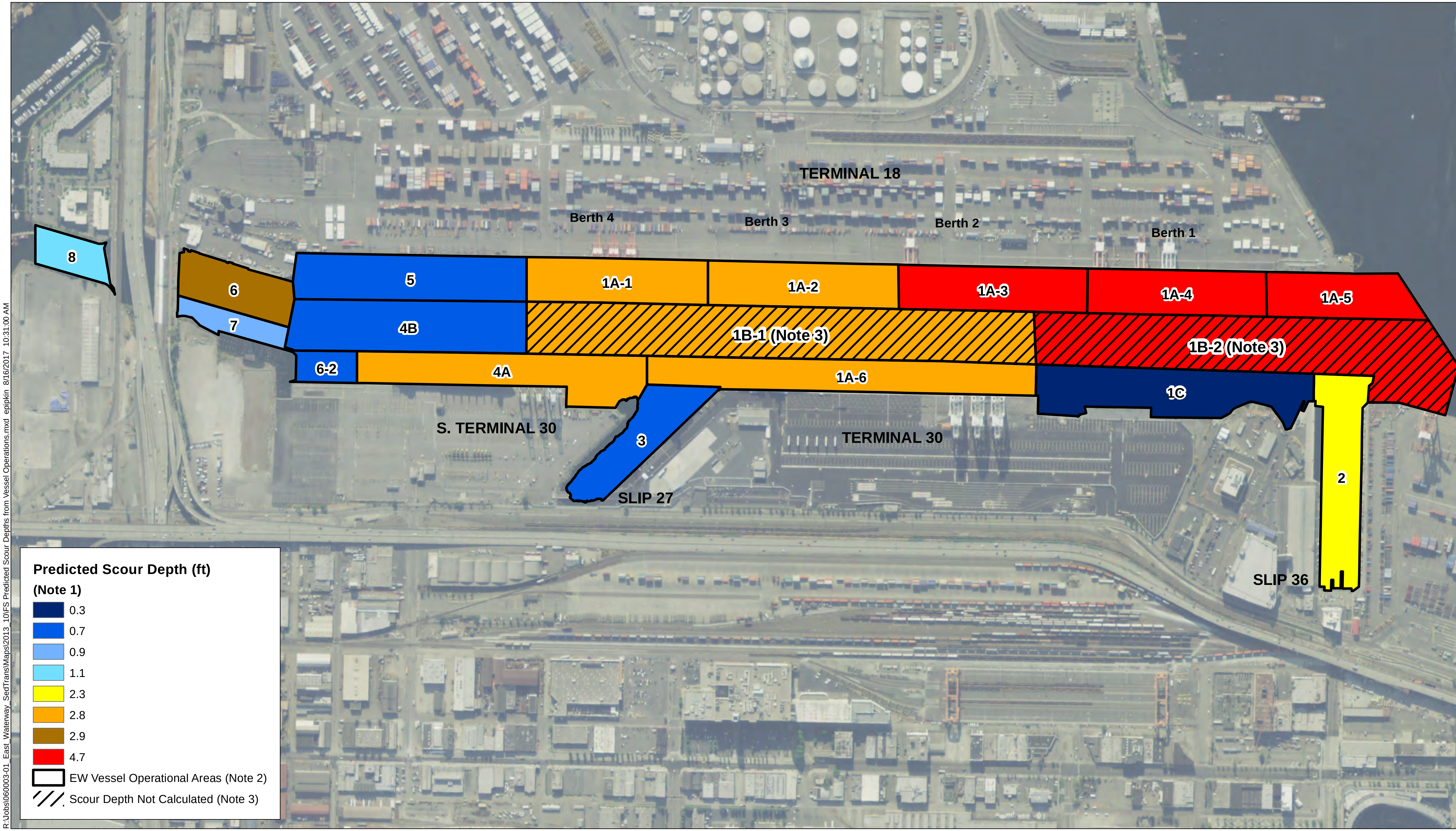


Q:\Jobs\060003-01 East Waterway SRI-FS\Maps\2015_07\NSR and Scour Areas.mxd epipkin 8/16/2017 10:08:13 AM

NOTES:
1. Vertical datum is MLLW, feet.
2. EW Vessel Operational Areas developed as part of the EW STER (Anchor QEA and Coast and Harbor Engineering, 2012); see Section 5.1.2 of the STER.
3. Cores collected in February 2010. Net sedimentation rates in cm/yr.

Feet
0 300 600 900 1,200

Figure 5-1
Geochronology Core Locations, Vessel Operations and Net Sedimentation Areas
Feasibility Study
East Waterway Study Area

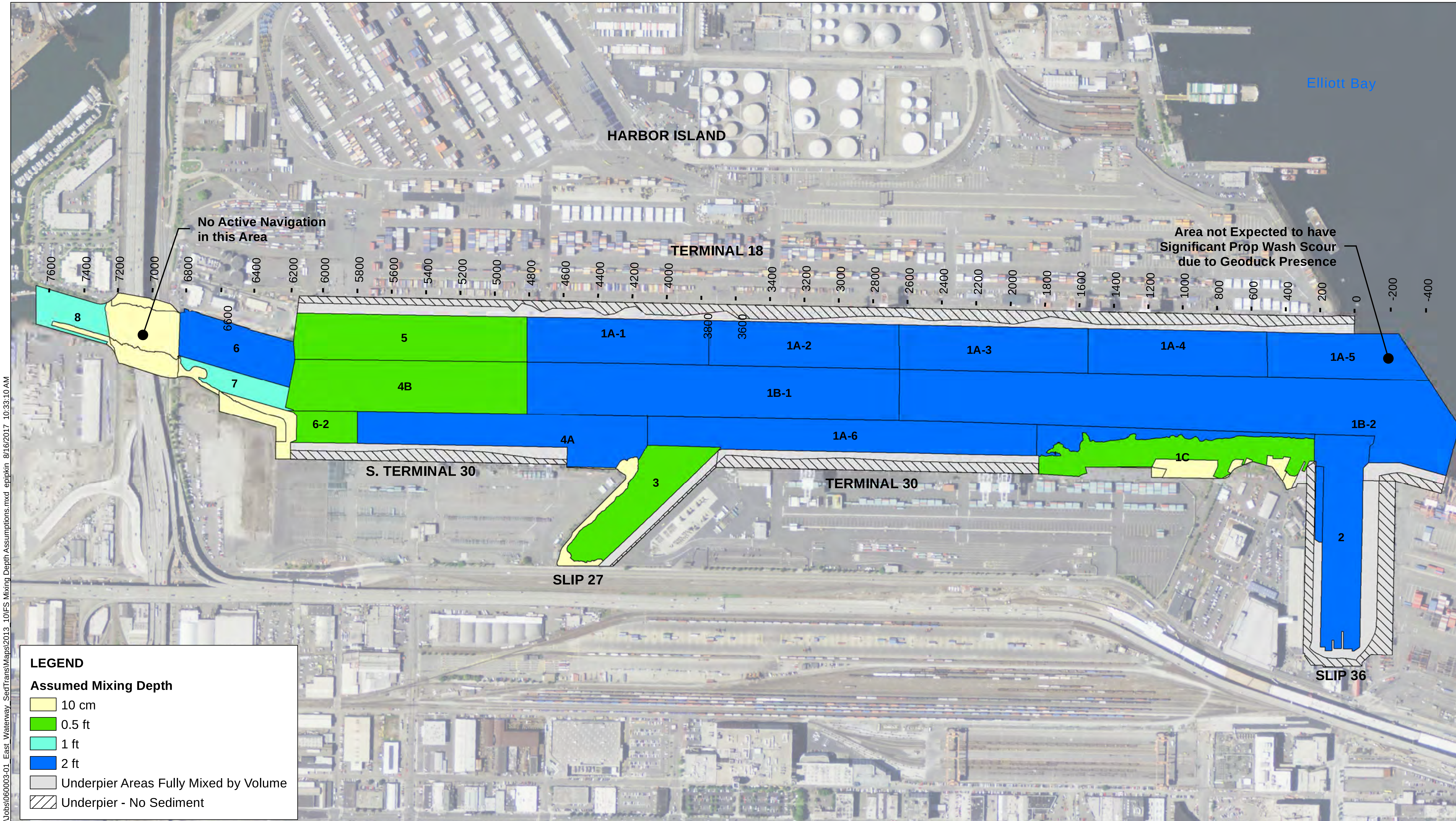


R:\Jobs\060003-01_East_Waterway_SedTrans\Maps\2013_10\FS Predicted Scour Depths from Vessel Operations.mxd epipkin 8/16/2017 10:31:00 AM

NOTES:
1. Calculations for scour depths provided in Appendix B, Part 2: Scour Depth Analysis Memorandum.
2. EW Vessel Operational Areas developed as part of the EW STER (Anchor QEA and Coast and Harbor Engineering, 2012); see Section 5.1.2 of the STER.
3. Areas 1B-1 and 1B-2 represent the navigation area between Terminal 18 and 30 berthing areas. Since berthing manuevers may begin within the navigation channel depending on weather or other site conditions, this area is expected to experience similar scour depths as the berthing areas.

Feet
0 250 500 750 1,000

Figure 5-2
Predicted Scour Depths from Vessel Operations
Feasibility Study
East Waterway Study Area



NOTE:
1. Aerial photo is NAIP, 2011.

Feet
0 250 500 750 1,000

Figure 5-3
Mixing Depth Assumptions
Feasibility Study
East Waterway Study Area

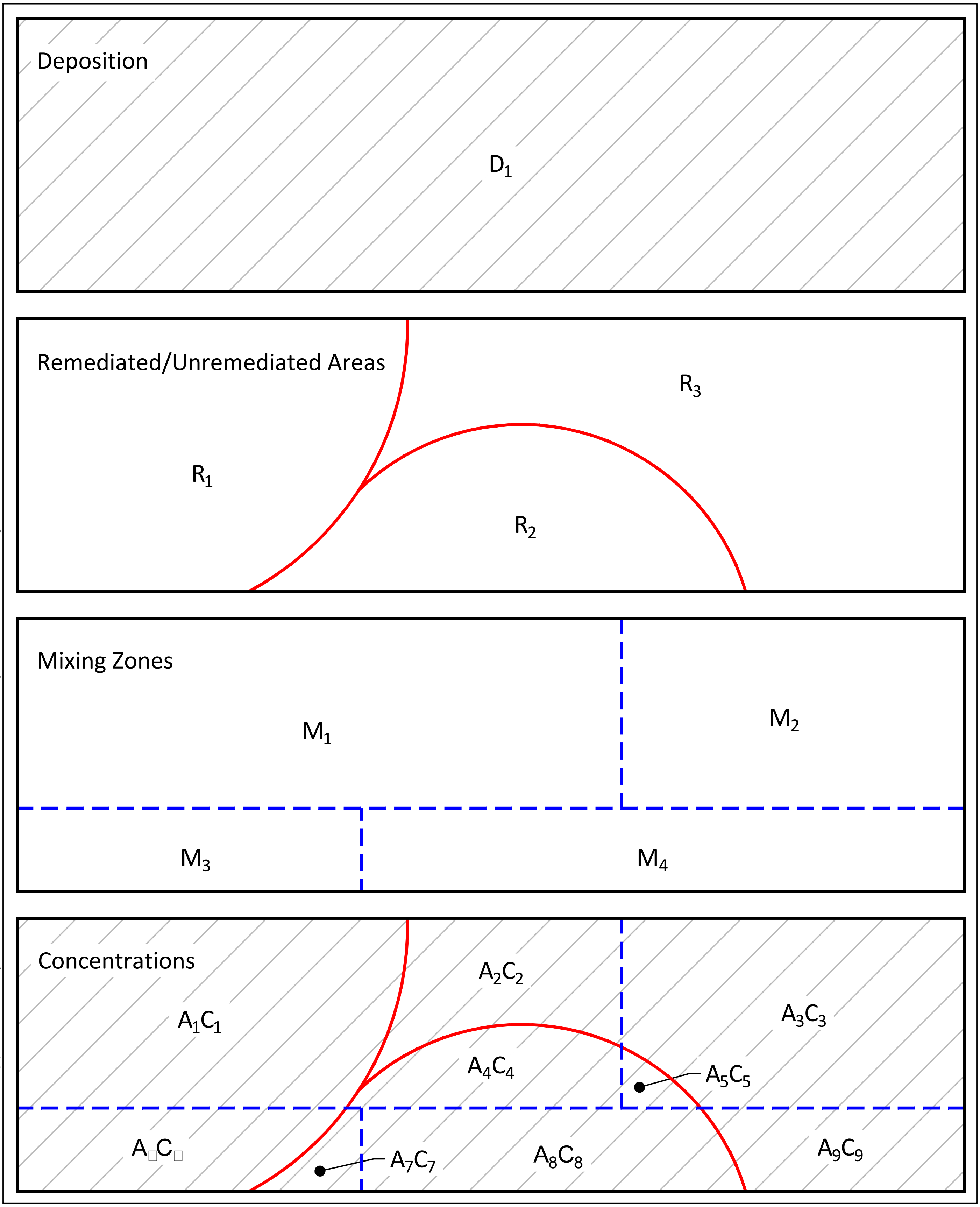


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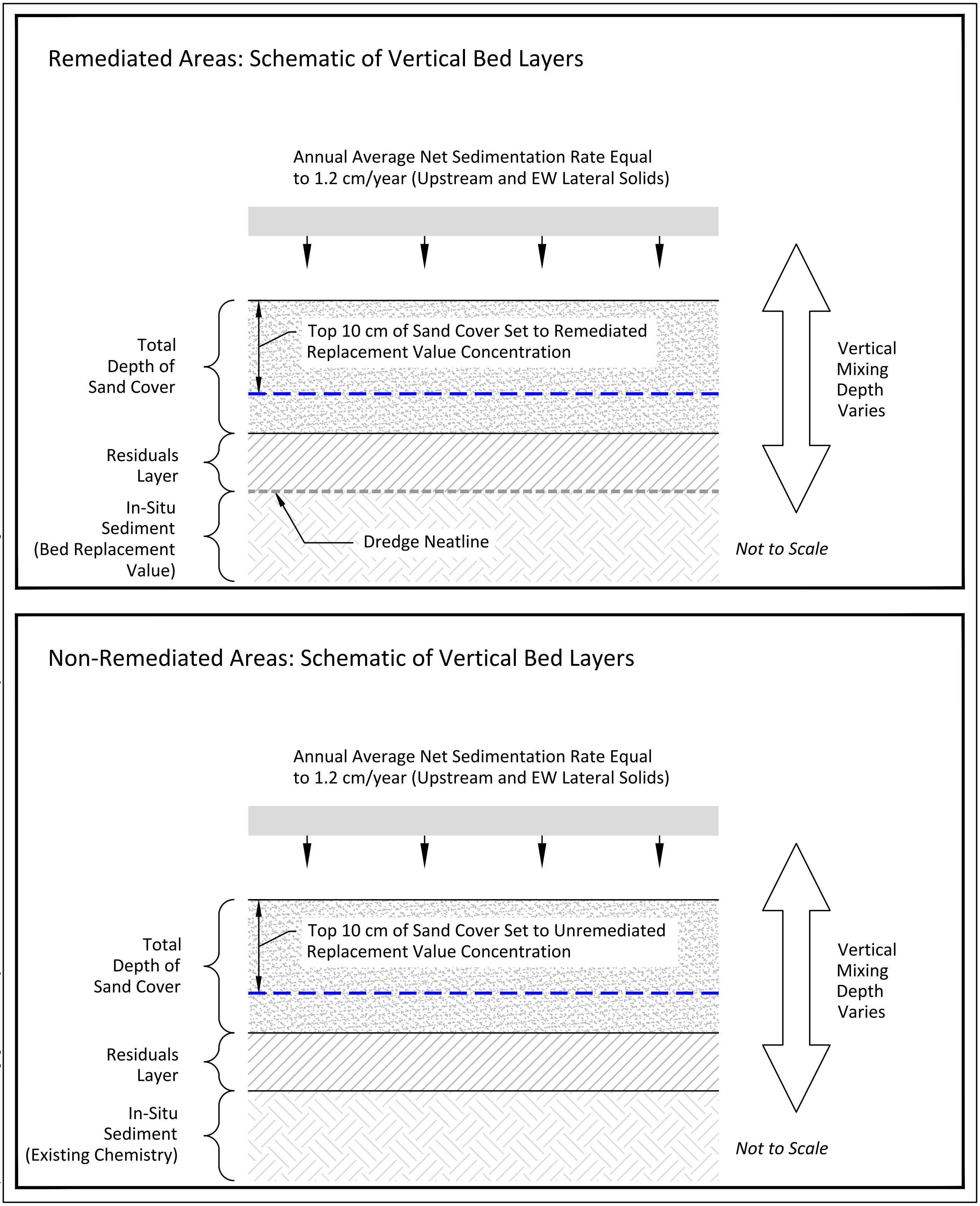
Figure 5-4
Conceptual Overview of Long-Term SWAC Calculation: Box Model Evaluation
Feasibility Study
East Waterway Study Area



NOTE: The conceptual examples above apply to locations in and near removal areas.
See Appendix J Figures 1a through 1j for additional location-specific conceptual cross-sections.

Figure 5-5
Conceptual Example of Bed Mixing Model Layers
Feasibility Study
East Waterway Study Area

NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.

Point Mixing Model Sample Location
Outfall Locations (within PTM Model)

0 500 1,000
Scale in Feet

Figure 5-6
Point Mixing Model Sample Locations
Feasibility Study
East Waterway Study Area

6 REMEDIAL ACTION LEVELS

This section defines the RALs and associated sediment areas of the EW OU requiring remediation. Some shoreline areas within the OU do not contain sediment, but are riprap slopes, as indicated in Figures 6-1 through 6-7. Only areas with sediment will be used to define the area requiring remediation (remediation area), for which remedial alternatives will be developed and evaluated. Consistent with EPA guidance (1988, 2005), delineation of the areas requiring remediation is based on findings of unacceptable risks in the ERA and HHRA (Windward 2012a, 2012b), site conditions, and technical practicability. The methods used to develop the RALs are described in Section 6.1; the rationale for the selection of the RALs is presented Section 6.2; and the RALs are summarized in Section 6.3.

RALs are contaminant-specific sediment concentrations that trigger the need for remediation (e.g., dredging, capping, or MNR). The RALs are designed to achieve RAOs. The RAOs (Section 4) can be achieved through combinations of remediation, natural recovery, and institutional controls. The areas requiring remediation will be refined during remedial design.

PRGs are the long-term cleanup goals for the project, whereas RALs are point-based values that define where remediation is to occur for a given remedial alternative. PRGs are the same for all alternatives. Three sets of RALs are evaluated for screening of alternatives (Appendix L), and two sets of RALs are retained for the detailed development and comparison of alternatives in the FS. RALs will also be used as the performance compliance criteria to verify that remediation for an area is complete, or successful, before equipment is demobilized from an area.

For this FS, RALs are developed for three of four human health risk drivers (total PCBs, arsenic, and dioxins/furans and excluding cPAHs [see Section 3.3.4]) as well as a subset of the ecological risk drivers,[76] which include TBT and a set of indicator SMS chemicals (i.e., selected risk driver contaminants detected above the SQS in surface sediments that represent the extent of SQS exceedances). RALs and associated remediation areas for these risk drivers are designed to address all COCs.

[76] Total PCBs were also identified as an ecological risk driver for fish (RAO 4). The total PCB PRG for human health is lower than the fish PRG, so the remediation area developed in consideration of human health will address risks for fish.

6.1 Methods Used for Development of RALs

This section briefly summarizes the methods used to develop the RALs that serve to define the area requiring remediation (i.e., the remedial footprint) and a corresponding range of expected outcomes based on the range of remedial alternatives (Section 8). The RALs for this FS were selected based on the following considerations:

- Certain sediment PRGs can directly translate into RALs, such as SMS benthic numerical criteria and the TBT RBTC applied on a point basis, which directly relate to protection of the benthic invertebrate community (RAO 3). Compliance with these PRGs is on a point basis.
- Certain PRGs—such as those for total PCBs, arsenic, and dioxins/furans—cannot be used directly as RALs because they are based on area-wide or site-wide average concentrations rather than being point-based (e.g., PRGs based on seafood consumption for RAO 1, or direct contact related to tribal netfishing for RAO 2). In these cases, RALs are developed to meet the site-wide or area-wide (i.e., clamming area) PRGs. Compliance with these PRGs is on an area-wide basis.[77]
- The PRGs for RAO 1 for PCBs and dioxins/furans are based on natural background concentrations. However, as presented in Appendix A, it may not be technically possible to achieve the PRGs for these two risk drivers for the following reasons:
  - The concentrations of these risk drivers from incoming Green/Duwamish River loadings and resuspended sediment in the LDW from scour events are predicted to be higher than natural background.
  - There are practical limitations on control of loadings from lateral sources (i.e., SDs and CSOs) from the LDW and EW drainage basins. Even with large investments in stormwater infrastructure, stormwater generated from urban areas during storm events will release some suspended solids to surface waters. These suspended solids are currently and will continue to be higher than natural background.

[77] While the FS uses model-generated SWACs for area-wide applied PRGs, compliance post-remediation will be determined based on the results of statistical comparisons to ROD-established cleanup levels (e.g., computing UCL95 with post-remediation site sediment data).

- There are constructability constraints within the EW (e.g., overwater structures and bridges; Appendix A), which affects the concentrations that can be achieved following cleanup.

The approach to selecting RALs to achieve RAO 1 is discussed in Section 6.2.2.

6.1.1 Data Used for Selection of RALs and Delineation of Remediation Footprints

The RALs are based on the types and levels of estimated risks in the EW (see Section 3), the RAOs to address those risks and associated PRGs (see Section 4), and the CSM, site conditions, and site data collection and analysis efforts (see Section 2).

The SRI/FS dataset for both surface and subsurface sediments provides a characterization of sediment contamination patterns within the EW. The data used to establish the area requiring remediation consist of detected concentrations of risk driver contaminants in surface sediment (0 to 10 cm) in the entire EW OU. In addition, north of the Spokane Street Bridge, the top 2 feet of sediment were also included because of the potential for propwash to expose this shallow subsurface sediment. These propwash forces do not occur under and south of the Spokane Street Bridge. Typically, data from the top 10 cm are used to delineate the areas requiring remediation since that is the biologically active zone and is the depth that human and other ecological receptors are likely to be exposed. However, since the EW OU is prone to deeper surficial mixing from vessel activity (as described in Section 5), the top 2 feet was also included in the evaluation. During design, it is anticipated that newly collected sediment samples will be used to refine the area above RALs.

6.1.2 Data Mapping and Interpolation Methods

6.1.2.1 Site-wide

The areas requiring remediation for each of the risk drivers were developed using Thiessen polygons, which are used to estimate the distribution of contaminant concentrations. Thiessen polygons were generated using risk driver concentrations in surface sediment throughout the entire OU and shallow subsurface sediment (0 to 2 feet) north of the Spokane Street Bridge.

A Thiessen polygon refers to the boundary of the area that surrounds a unique data point. Thiessen polygons are a commonly used method for characterizing the distribution of sediment chemical contamination and biological effects by assigning chemical concentrations or other values to areas where no actual data exist (i.e., un-sampled areas). Thiessen polygons have boundaries that define the area that is closest to each point relative to all other points. The polygon size and shape is determined by the proximity of neighboring sample locations. The concentration within the entire polygon is assumed to be equal to the concentration of the sample point located at the centroid. Thus, every un-sampled area is assigned the value of its nearest measurement point.

In using Thiessen polygons, each sample point concentration is assumed to contribute to the area-wide mean concentration according to the relative size of the polygon area it represents. Interpolation using Thiessen polygons is a reasonably unbiased method when the distance between sample points is relatively small, because accuracy depends largely on sampling density. However, when sampling locations are spaced several hundred feet apart, the uncertainty in this assumption increases (as with any interpolation method). Areas of dense sampling are characterized by relatively small polygons, whereas areas of sparse sampling are characterized by relatively large polygons.

Thiessen polygons were determined to be an appropriate interpolation method to evaluate the extent of COC concentrations throughout the entire OU due to the high density of data points with good spatial distribution. Additional details on the evaluation and sensitivity of interpolation methods are presented in Appendix C. During design, remediation areas will be further refined (e.g., edges or borders of areas delineated for remediation in the FS), and final areas and volumes requiring remediation will be refined as a result.

Development of the area requiring remediation was based on a stepwise process using both the surface (0 to 10 cm) and shallow subsurface (0 to 2 feet) sediment concentrations. First, surface (0 to 10 cm) sediment sample locations were used to develop Thiessen polygons throughout the entire OU. These Thiessen polygons were compared to SMS criteria for each risk driver using the combined chemistry and toxicity test results. However, samples above SMS criteria (SQS or CSL) for total PCBs were considered to be above SMS criteria regardless of the toxicity test result (which typically would have priority over the chemical results) because PCBs are also a human health risk driver with a PRG for the protection of human health that is lower than the benthic PRG (i.e., SQS).[78] Then, sample locations with subsurface sediment (0 to 2 feet) were added,[79] and new Thiessen polygons were generated in the entire OU. Each of these polygons above SMS criteria were added to the area requiring remediation. As such, if the surface sediment or shallow subsurface sediment (0 to 2 feet) had concentrations above a RAL, the area was included in the remediation area (i.e., either the surface or shallow subsurface could specify the area for remediation). For example, if the shallow subsurface sediment (0 to 2 feet) had concentrations below that RAL, but the surface sediment (0 to 10 cm) had concentrations above the RAL, then the area was designated a remediation area.

As noted in Appendix H, Section 2, cores that were sampled in intervals larger than the upper 2 feet of sediment were not used for establishing remediation areas. For example, if a core had a sample interval of 0 to 3 feet, it was not used to determine if remediation is necessary at that location because the contamination could have been deeper than 2 feet. Instead, all other nearby surface sediment and shallow subsurface cores with an upper interval of 2 feet or less were used. Most of the cores with upper intervals larger than 2 feet are located in the Shallow Main Body Reach, where the mixing depth from propwash is estimated to be 0.7 foot, suggesting contamination present below that depth is unlikely to be exposed due to propwash. The remediation footprint will be refined in design.

6.1.2.2 Intertidal Areas

The extent of the intertidal areas that could potentially be subject to clamming activities include exposed areas without overwater dock structures that contain at least some exposed sediment (and are not entirely riprap shoreline areas). Currently, 1.4 acres contains exposed sediment where clamming could occur. However, potential clamming areas could be expanded depending on future use, as discussed in Section 2.9.4. Therefore, an expanded area

[78] Total PCBs were also identified as an ecological risk driver for fish (RAO 4). The total PCB PRG for human health is lower than the fish PRG, so the remediation area developed in consideration of human health will address risks for fish.

[79] This includes results collected following completion of Phase 1 dredging but prior to placement of the residuals management sand cover layer.

comprising a total of approximately 4 acres (see Figure 2-11) will be referred to as potential exposed intertidal clamming areas, which will be used for evaluation of RAO 2, the human health direct contact tribal clamming exposure scenario. Other intertidal areas that are entirely riprap (i.e., riprap not overlain by sediment) or are not exposed because they are beneath an overwater apron or pier are not included in the intertidal area evaluated for RAO 2 (see Figure 2-11).

For the potential exposed intertidal clamming areas, arsenic concentrations (the risk driver COC for RAO 2) was estimated for individual intertidal polygons using the available data considered most representative of arsenic concentrations in these areas. Intertidal polygons were developed based on the locations of the 15 intertidal beach composite samples (Figure 6-5). The exposed intertidal area in the entire waterway was divided into individual polygons, with one polygon representing each area where intertidal composite samples were collected. These polygons are more representative than polygons based on subtidal samples in this area since intertidal composite samples were collected specifically to represent the SWAC for the area sampled to estimate potential direct contact exposure. One additional polygon was added adjacent to the southern opening of Slip 36 where additional exposed intertidal habitat is present (but no intertidal composite samples were collected; see inset on Figure 6-5).

Arsenic concentrations were estimated for each intertidal polygon based on the weighted average of intertidal and subtidal sample-derived Thiessen polygons that extend into the accessible intertidal area (presented in Section 6.2.3).

6.1.3 Uncertainty Analysis

This section examines potential uncertainties in the dataset used for establishing the horizontal extent of remediation using the criteria discussed in Sections 6.1 and 6.2. The primary factors contributing to uncertainty are the age of the data and data mapping and interpolation. Overall, the nature and extent of risk driver chemicals are sufficiently understood to characterize risks and develop reasonable estimates of the areas requiring remediation, and identifying the site-wide remedial alternatives for the FS. Refinement of sediment contamination above selected RALs will be based on additional data collection during remedial design, thereby reducing associated uncertainties.

6.1.3.1 Age of Data

The surface and shallow subsurface (0 to 2 feet) sediment data were used to map the area requiring remediation. One rule used to define the SRI/FS baseline dataset is the replacement of older data at stations that were resampled (defined as falling within 10 feet of newer data). This evaluation was conducted on a chemical-by-chemical basis at each older station within 10 feet of a newer station. The intent of this effort was to use the most recent data available for defining the nature and extent of chemical contamination. However, because not all of the older data were co-located with newer data, the FS baseline dataset comprises surface sediment samples spanning 15 years of data collection efforts (1995 to 2010) and subsurface samples spanning 19 years of data collection efforts (1991 to 2010). While it is possible that surface and shallow subsurface conditions have changed in these sampled areas, most of this data collection has occurred in the recent past. More than 80% of the surface and subsurface data has been collected within the last 10 years, thus reducing the uncertainty.

The FS accepts this level of uncertainty by assuming that all data represent current conditions. Remedial alternatives are assembled based on these data along with other lines of evidence described in Section 8. However, sampling conducted during remedial design will reduce this uncertainty.

6.1.3.2 Data Mapping and Interpolation

The SRI/FS baseline dataset contains data from numerous site investigations compiled together to determine the nature and extent of sediment contamination associated with past chemical releases. This extensive dataset was used to build the CSM, map the nature and extent of contamination, and understand site processes for evaluating remedial alternatives. However, as with every environmental investigation, some uncertainty remains associated with the horizontal and vertical extent of sediment contamination, as discussed in the following points:

- **Laboratory Reporting Limits:** A portion of the uncertainty is related to reporting limits for non-detects that exceed the screening criteria, RALs, or the PRGs, especially in older data. Therefore, the area requiring remediation was delineated using only detected SQS exceedance concentrations in the point data (expressed spatially as Thiessen polygons). However, this uncertainty is relatively minor, as described in the uncertainty section of the ERA (Windward 2012a) and Section 4 of the SRI (Windward and Anchor QEA 2014), in which nine contaminants had RLs exceeding the SQS, and less than 15% of the results for those nine contaminants were non-detects with the RLs exceeding the SQS. Appendix C presents samples with non-detected results with RLs that are greater than the SQS and are outside of remedial footprints. It is anticipated that at least 77% of the EW OU will be remediated, further reducing the impact of the uncertainty of laboratory reporting limits.

- **Sampling Design**: Another portion of uncertainty is related to the design of the various past sampling programs represented in the SRI/FS baseline dataset. A few historical investigations have targeted specific areas (e.g., the Phase 1 dredge area) and, therefore, have much denser sampling coverage than other areas of the EW. The experimental designs for collecting SRI samples were developed in consultation with EPA to achieve adequate spatial representation throughout the entire study area, considering existing data determined to be acceptable for use in the SRI and FS.[80] Good spatial coverage exists throughout the EW; however, sample locations in some areas are more evenly distributed than others. For this reason, the areal extent of contamination has some uncertainty, which is common in the feasibility study phase of any project. However, since most of the EW OU is within the remediation area, this uncertainty is relatively small. The delineation will be refined during remedial design.
- **Interpolation Methods:** Thiessen polygon interpolation methods were used to map surface sediment and shallow subsurface sediment data. These methods, like all interpolation methods, have inherent uncertainties, including the density of samples, influence of geomorphology on the distribution of contaminants, and influence of surrounding data. The selected Thiessen polygon technique is well documented and widely used for managing contaminated sediments. Appendix C presents the rationale

[80] To refine the extent of known contaminated areas, additional sampling may be needed during remedial design. Design sampling will be conducted to refine the areal extent of the cleanup area and vertical extent of contaminated sediments.

for this interpolation method and presents a sensitivity analysis with comparison to another interpolation method.

6.2 Selection of RALs

This section describes the selected RALs and how they were established to achieve each RAO. Once remediation is completed, the achievement of the RAO-specific PRGs is determined based on a site-wide average concentration for RAOs 1, 2, and 4; clamming area average concentrations for RAO 2, and on a point basis evaluation for RAO 3.

RALs are presented below in a stepwise manner, with each RAL resulting in additional area requiring remediation. The remediation area was first developed based on the protection of benthic invertebrates (RAO 3) because RALs based on RAO 3 risk drivers (including PCBs and arsenic) generate the majority of the remediation area. These RALs are based on SMS benthic numerical criteria (these are the RBTCs for benthic community) and the TBT RBTC (Figure 6-1). Then, additional remediation areas were added based on RALs for total PCBs and dioxins/furans, because these RALs add the second largest remediation area (Figures 6-3 and 6-4). The area requiring remediation was delineated where any of these compounds exceeded the RAL concentrations described below.

6.2.1 RAO 3 (Protection of Benthic Invertebrates) RAL

The area requiring remediation includes locations with detected concentrations of the benthic community risk drivers above the SQS (RALs are equal to the RAO 3 PRGs). Each Thiessen polygon shown on Figure 6-1 was classified as an SQS exceedance if one or more detected SMS contaminants exceeded this criterion in the 0- to 10-cm interval of sediment or 0- to 2-foot interval of subsurface sediment north of the Spokane Street Bridge (see Section 6.1.2.1). Toxicity test results were included in the final classifications with passing toxicity results trumping the chemistry results, except for polygons that exceeded the SQS for PCBs because PCBs are also a human health COC. The OC-normalized concentrations were used for total PCBs and other non-polar organic compounds when the TOC content was within the appropriate range for OC-normalization (0.5% to 4.0%); otherwise dry weight LAET values were used to establish whether a sample was above or below SMS criteria.[81] The PRGs for SMS chemicals are expected to be achieved site-wide immediately after construction in open-water areas.

For RAO 3, the area requiring remediation was expanded to include locations with TBT concentrations above the RBTC (and, thus, PRG). The density and spatial extent of TBT sample locations were not adequate to develop area-wide Thiessen polygons. Therefore, each surface sediment or shallow subsurface sediment location (north of the Spokane Street Bridge) that was analyzed for TBT was compared to the RBTC of 7.5 mg/kg OC (Figure 6-1). All TBT sample locations exceeding the RBTC are already included in the area requiring remediation based on SMS criteria exceedances, except for one sample from the 0- to 2-foot interval at EW-SC100. For that location, a polygon was constructed to encompass an estimated exceedance area, using best professional judgement considering the chemical data from nearby samples for TBT and other benthic risk driver COCs (area shown on Figure 6-1). The PRG for TBT is expected to be achieved immediately after construction in open-water areas.

As shown on Table 4-5, 29 risk driver COCs exceeded the SQS. RALs were not developed for all of these benthic risk drivers, rather RALs were developed for a subset of these risk drivers (referred to as indicator SMS chemicals). These indicator SMS chemicals consist of 1,4-dichlorobenzene, acenaphthene, arsenic, butyl benzyl phthalate, fluoranthene, fluorene, mercury, phenanthrene, and total PCBs. RALs are not established for each of the other benthic risk driver COCs (e.g., other SMS contaminants) because site-specific analysis shows that remediation to address these nine contaminants also addresses the other SMS contaminants that are above the SQS. This analysis was performed using the project database: surface sediment and shallow subsurface samples (Section 6.1.1) that exceeded the RALs for any of the nine indicator COCs were removed from the dataset, resulting in no additional benthic exceedances remaining. This shows that at least one of the nine indicator COCs are always co-located with the remaining benthic COCs. Thus, based on analysis of the SRI/FS dataset, the subset of SMS chemicals represents the full extent of SQS exceedances in surface and shallow subsurface

[81]The lowest-apparent-effect threshold (LAET) is used as the dry weight equivalent to SQS for compounds with organic carbon-nomalized criteria for samples outside of the appropriate total organic carbon range. The second-lowest-apparent-effect threshold (2LAET) is used as the dry weight equivalent to benthic CSL for compounds with organic carbon-nomalized criteria for samples outside of the appropriate total organic carbon range for carbon-normalizing. LAET and 2LAET values can be found in SCUM II (Ecology 2017).

sediments. Note that the depth of contamination determined by the indicator chemicals also encompasses exceedances from the full set of risk driver COCs. The area requiring remediation above the RALs for RAO 3 constitutes 120 acres, or 76% of the OU (Figure 6-1).

Refinement to the remediation area, as necessary, considering all benthic risk driver COCs will be determined during remedial design. All SMS COCs will be monitored after remediation and monitoring will determine if additional actions are warranted.

6.2.2 RAO 1 (Human Health Seafood Consumption) RALs

For this FS, progress toward achievement of RAO 1 (reduction of human health risks from seafood consumption) is assessed based on estimated reductions in the site-wide SWAC of total PCBs and dioxins/furans. cPAHs were also identified as a risk driver for RAO 1, and are discussed in this section.

The total PCB and dioxin/furan PRGs for RAO 1 are based on natural background concentrations in this FS. Because PRGs based on natural background are not expected to be achieved (Appendix A), RALs were developed to reduce site-wide SWACs which would, in turn, reduce associated risks for RAO 1. Table 6-1 presents the RALs and their predicted outcomes with respect to SWACs and RAOs.

Because the PCB PRG of natural background for RAO 1 cannot be achieved in the EW, three different RALs were developed and screened to evaluate effectiveness, cost, and implementability of the RALs (see Appendix L for more details). For total PCBs, a "hill-topping" evaluation was conducted to select the screening RALs by ranking the measured surface and shallow subsurface sediment PCB concentrations from highest to lowest. The highest values were sequentially replaced with a post-remedy bed sediment replacement value (see Appendix B Part 3) to estimate the site-wide SWAC after each of the values (and associated estimated remediation area) was removed from the dataset. Figure 6-2 presents the hill-topping results for total PCBs, showing the relationship between RAL, area remediated, and resulting SWAC. Note that the analysis is performed on dry weight concentrations; however, PCB RALs are measured as carbon-normalized concentrations, to be consistent with the marine benthic standard and to acknowledge the role of organic carbon in PCB bioavailability.

The hill-topping results shown on Figure 6-2 informed the selection of the three screening RALs for total PCBs: 12 mg/kg OC (equivalent to 192 µg/kg dw), 7.5 mg/kg OC (equivalent to 120 µg/kg dw), and 5.0 mg/kg OC (equivalent to 80 µg/kg dw).[82] As shown in Figure 6-2, each of these screening RALs is below the "knee of the curve," or the point at which further reductions in the RAL does not result in an appreciable reduction in the site-wide SWAC. The hill-topping also demonstrates that all three PCB RALs in Figure 6-2 are similar to the best estimate of incoming sediment concentrations, limiting the possibility that site-wide concentrations would increase due to incoming sediment following remediation. Figure 6-3 shows the remediation areas associated with these three screening RALs for PCBs, along with the RALs for the other COCs.

PCB RALs retained for detailed evaluation are 12 mg/kg OC and 7.5 mg/kg OC. The 12 mg/kg OC RAL is the highest RAL considered because it is the same as the PRG for protection of benthic invertebrates (RAO 3) and achieves the PRG for protection of ecological health (RAO 4). The second PCB RAL of 7.5 mg/kg OC was selected to evaluate the effect of a lower RAL in the FS (Appendix L).

An additional screening RAL for total PCBs of 5.0 mg/kg OC was considered for inclusion in the detailed evaluation of alternatives. However, the RAL was screened out because it does not result in a decrease in SWAC beyond that achieved by the RAL of 7.5 mg/kg OC (Appendix L).

A dioxin/furan RAL of 25 ng TEQ/kg dw was selected for consistency with the LDW ROD (EPA 2014) and to achieve the lowest achievable concentrations in the EW. The area of the EW requiring remediation was expanded beyond the area identified based on RAO 3 to include any dioxin/furan concentrations above the RAL of 25 ng TEQ/kg dw measured in discrete surface and shallow subsurface sediment samples. Based on this criterion, three Thiessen polygons were added to the area requiring remediation to address dioxin/furan RAL

[82] All dry weight equivalents are based on average TOC of 1.6% in EW surface sediments.

exceedances (Figure 6-4). Two polygons were added based on two surface sediment sample concentrations above the RAL, and one polygon within Slip 27 was added because the subtidal composite sample representing Slip 27 is above the dioxin/furan RAL.

cPAHs were also identified as a risk-driver for RAO 1, but an RBTC could not be developed. As discussed in Section 3.3, sediment RBTCs based on the seafood consumption pathway were not calculated for cPAHs because correlation between sediment contaminant concentrations and clam tissue concentrations (the seafood type resulting in unacceptable human health risk) could not be established. However, achieving PRGs for RAO 3 are expected to also reduce sediment cPAH concentrations and the risk associated with the consumption of seafood. Though, consistent with the LDW, data showed little relationship between clams and sediment for cPAHs, and thus the amount of risk reduction from sediment remediation is unknown. The clam concentrations may be more related to the water pathway, and water exposures can be related to incoming water from upstream or downstream of the site.

When adding together the remediation areas for protection of RAO 1 to the remediation area for protection of RAO 3 (which includes the PCBs RAL of 12 mg/kg OC), the remediation area increases to 121 acres (1 additional acre) by incorporating the dioxin/furan RAL of 25 ng TEQ/kg dw (77% of the sediment area). The remediation footprint increases to 132 acres when expanding the area for the PCB RAL of 7.5 mg/kg OC (84% of the sediment area).

6.2.3 RAO 2 (Human Health Direct Contact) RALs

Achievement of RAO 2 is assessed on two spatial scales using two direct contact exposure scenarios: 1) site-wide for tribal netfishing; and 2) area-wide within existing and potential future clamming areas based on tribal clamming. Achieving the clamming PRG for RAO 2 requires that average sediment COC concentrations be reduced at locations and depths where people that are clamming have the potential to be exposed to sediment. Direct contact risks in the exposed intertidal areas (e.g., sediment areas not under pier) are assumed to result from exposure to the upper 25-cm depth interval. Arsenic is the risk driver COCs for direct contact. For arsenic, the same RAL (57 mg/kg dw applied site-wide) that achieves RAO 3 also achieves RAO 2; it provides overall reductions in sediment concentrations that achieve both the netfishing and clamming PRGs. Areas above the RALs for arsenic are shown in Figure 6-5.

When including site-wide remediation for all RALs (including either 12 mg/kg OC or 7.5 mg/kg OC for total PCBs), 3.3 acres, or 82% of the exposed intertidal area, will be remediated to achieve RAO 2.

6.2.4 RAO 4 (Ecological Receptor Seafood Consumption) RAL

For RAO 4, total PCBs is the only risk driver. Achievement of the PRG is assessed on a site-wide basis. Both the total PCB RALs of 7.5 mg/kg OC and 12 mg/kg OC are predicted to achieve RAO 4 immediately after construction, so no additional areas have been added based on this RAO.

6.3 Summary of RALs

The RALs are summarized in Table 6-1 based on the selection process described in Section 6.2. Figure 6-6 shows the entire remediation area based on these RALs. When adding together the remediation areas needed to address all RAOs, the remediation area is 121 acres when using the PCB RAL of 12 mg/kg OC (77% of the sediment area)[83] and 132 acres when using the PCB RAL of 7.5 mg/kg OC (84% of the sediment area).

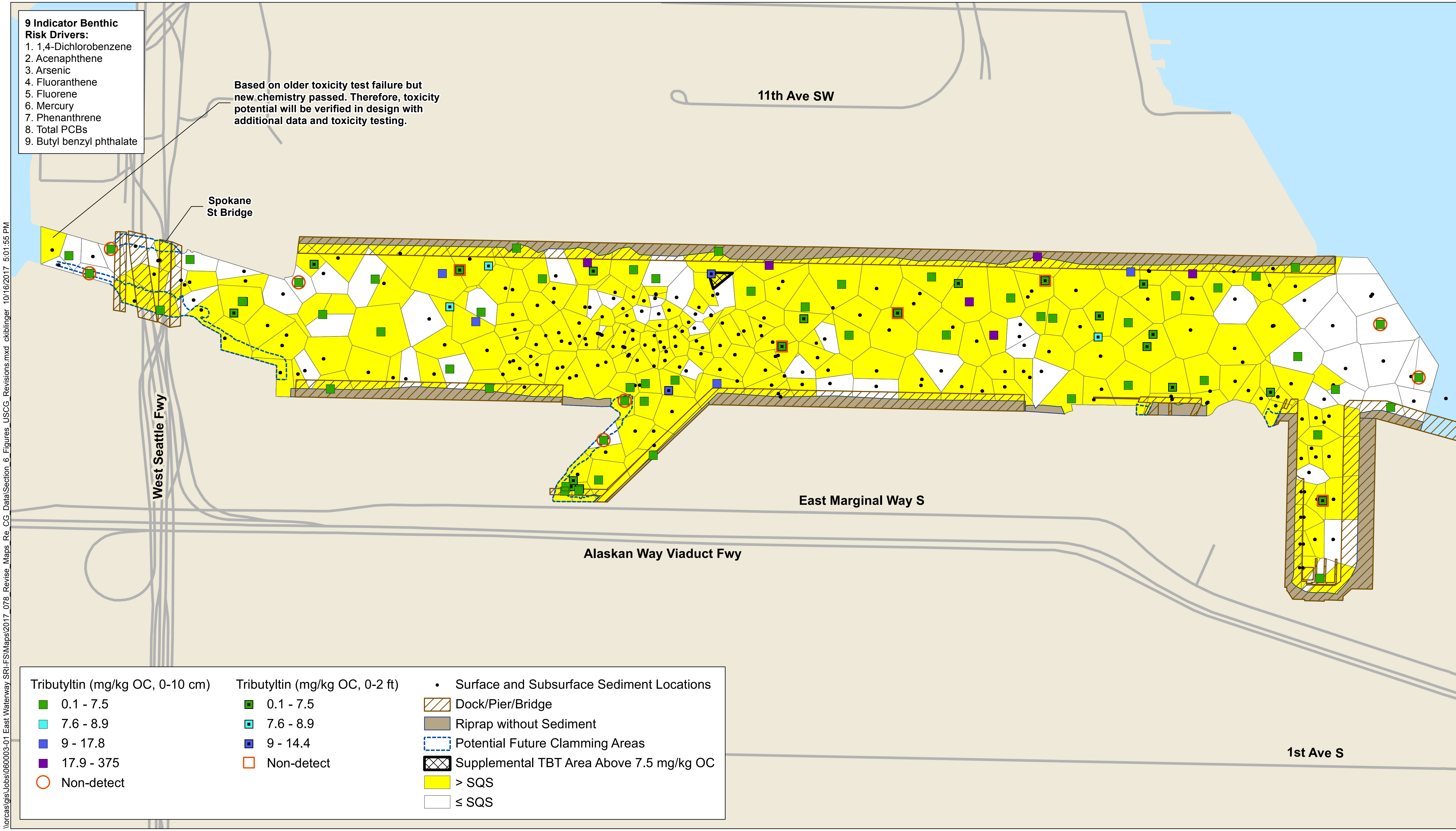
[83] As noted in Figure 6-6, a 0.11-acre modification area is shown as part of the 121-acre remediation area. However, this 0.11-acre area should be removed from the 121-acre remediations area (but retained within the larger 132-acre remediation area), due to a modification in the benzo(a)pyrene cancer slope factor used for cPAHs that occurred during the development of the FS. Because the modification area was not sufficiently large to alter the rounded areas, volumes, and costs for the alternatives, it has been retained as part of the 121-acre remediation area. As discussed elsewhere in the FS (e.g., Appendix G), the remediation areas will be further delineated with additional sampling during remedial design.

Table 6-1
Summary of Selected RALs

Risk Driver	RAL[a]	Data Used for Evaluation[a]	Approximate Post-construction Outcome[b,c]	PRG[d]	Remedial Action Objectives Achieved			
					RAO 1 (Human Health Seafood Consumption)	RAO 2 (Human Health Direct Contact)	RAO 3 (Protection of Benthic Invertebrates)	RAO 4 (Ecological-Fish)
Total PCBs	12 mg/kg OC (site-wide); 7.5 mg/kg OC (site-wide)	Site-wide Thiessen polygons[e]	Achieves 12 mg/kg OC on a point basis	12 mg/kg OC	NA	NA	✓	NA
			Site-wide SWAC of 40 µg/kg dw for both RALs (Appendix L)[f]	2 µg/kg dw	**T**	NA	NA	NA
				250, 370 µg/kg dw	NA	NA	NA	✓
Arsenic (mg/kg dw)	57 (site-wide)	Site-wide Thiessen polygons[e]	Achieves 57 on a point basis	57	NA	NA	✓	NA
			Site-wide SWAC of 12	7	NA	✓	NA	NA
	57 (clamming areas)	Intertidal polygons[g]	Clamming area SWAC of 12	7	NA	✓	NA	NA
Dioxins/furans (ng TEQ/kg dw)	25 (site-wide)	Site-wide Thiessen polygons[e]	Site-wide SWAC of 5[h]	2	**T**	NA	NA	NA
Tributyltin (mg/kg OC)	7.5 (site-wide)	Site-wide Thiessen polygons[e]	Achieves 7.5 on a point basis	7.5	NA	NA	✓	NA
SMS Chemicals[i]								
1,4-dichlorobenzene (mg/kg OC)	3.1	Site-wide Thiessen polygons[e]	Achieves 3.1 on a point basis	3.1	NA	NA	✓	NA
Butyl benzyl phthalate (mg/kg OC)	4.9		Achieves 4.9 on a point basis	4.9				
Acenaphthene (mg/kg OC)	16		Achieves 16 on a point basis	16				
Fluoranthene (mg/kg OC)	160		Achieves 160 on a point basis	160				
Fluorene (mg/kg OC)	23		Achieves 23 on a point basis	23				
Mercury (mg/kg dw)	0.41		Achieves 0.41 on a point basis	0.41				
Phenanthrene (mg/kg OC)	100		Achieves 100 on a point basis	100				
Total PCBs (mg/kg OC)	12		Achieves 12 on a point basis	12				
Arsenic (mg/kg dw)	57		Achieves 57 on a point basis	57				

Notes:
a. Point concentrations used to develop site-wide polygons to delineate the area requiring remediation. Intertidal composite concentrations used to develop exposed intertidal polygons to delineate the area requiring remediation.
b. Effective site-wide SWAC is the post remediation SWAC combining both the post remediation SWAC from the areas requiring remediation for all the RALs listed above with the SWACs from the areas below RALs.
c. Replacement values for remediated areas and internal unremediated areas developed and presented in Section 5 were applied for calculation of effective site-wide and intertidal SWACs.
d. PRGs were developed and presented in Section 4.
e. Based on surface (0 to 10 cm) sediment and shallow (0 to 2 feet) subsurface sediment.
f. When considering all COCs that make up the full remediation area, as presented in Appendix L, the effective site-wide SWAC for the RALs of 12 mg/kg OC and 7.5 mg/kg OC were 40 µg/kg when considering effective bioavailability. Effective bioavailability estimates assume a 70% reduction in concentration in remediated underpier areas due to placement of in situ treatment material (see Section 7.2.7.1 for more details). SWACs for PCBs may be higher than indicated due to mixing of sediment left behind due to structural offsets (e.g., underpier areas, keyways, and associated dredging offsets) and dredge residuals (Appendix A). The screening RAL of 5.0 mg/kg OC also achieved similar SWACs (Appendix L).
g. Based on sediment collected from 0 to 10 cm (surface sediment grabs) and 0 to 25 cm (intertidal composites) in intertidal areas.
h. Dioxin/furan surface sediment subtidal composites were used to represent the concentration of unremediated areas for calculation of effective site-wide SWAC.
i. 29 risk driver COCs exceeded the SQS. RALs were selected for nine of these contaminants to represent the entire area above the SQS.
✓ – Achieves PRG immediately following construction or long-term model-predicted concentration.
T – Achieves RAO over time by reducing risks to human health. Institutional controls will be required to further reduce RAO 1 risks for PCBs and dioxins/furans. Compliance with the RAO in the long term will be demonstrated in one of several ways following SMS and CERCLA requirements (see Section 4.3.1).

µg – micrograms
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
COC – contaminant of concern
dw – dry weight
kg – kilograms
mg – milligrams
NA – not applicable
NB – natural background
ng – nanograms
OC – organic carbon
PCB – polychlorinated biphenyl
PRG – preliminary remediation goal
RAL – remedial action level
RAO – remedial action objective
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SWAC – spatially-weighted average concentration
TEQ – toxic equivalent



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NOTES:
1. Thiessen polygons shown include surface sediment polygons (presented in Figure 2-20a-c), further subdivided using shallow subsurface sediment results (0-2 ft) in the area north of the Spokane Street Bridge.
2. Shallow subsurface sediment results were only used to increase (but not decrease) the area exceeding SQS established based on surface sediment data.
3. Benthic toxicity bioassay data resulted in five polygons with chemical exceedances (for chemcals other than PCBs) being removed from the exceedance footprint.
4. Tributyltin RAL = 7.5 mg/kg-OC.

0 250 500 750 1,000
Scale in Feet

Figure 6-1
Benthic Risk Drivers: Exceedances of SQS for Surface Sediment and Shallow Subsurface Sediment
Feasibility Study
East Waterway Study Area

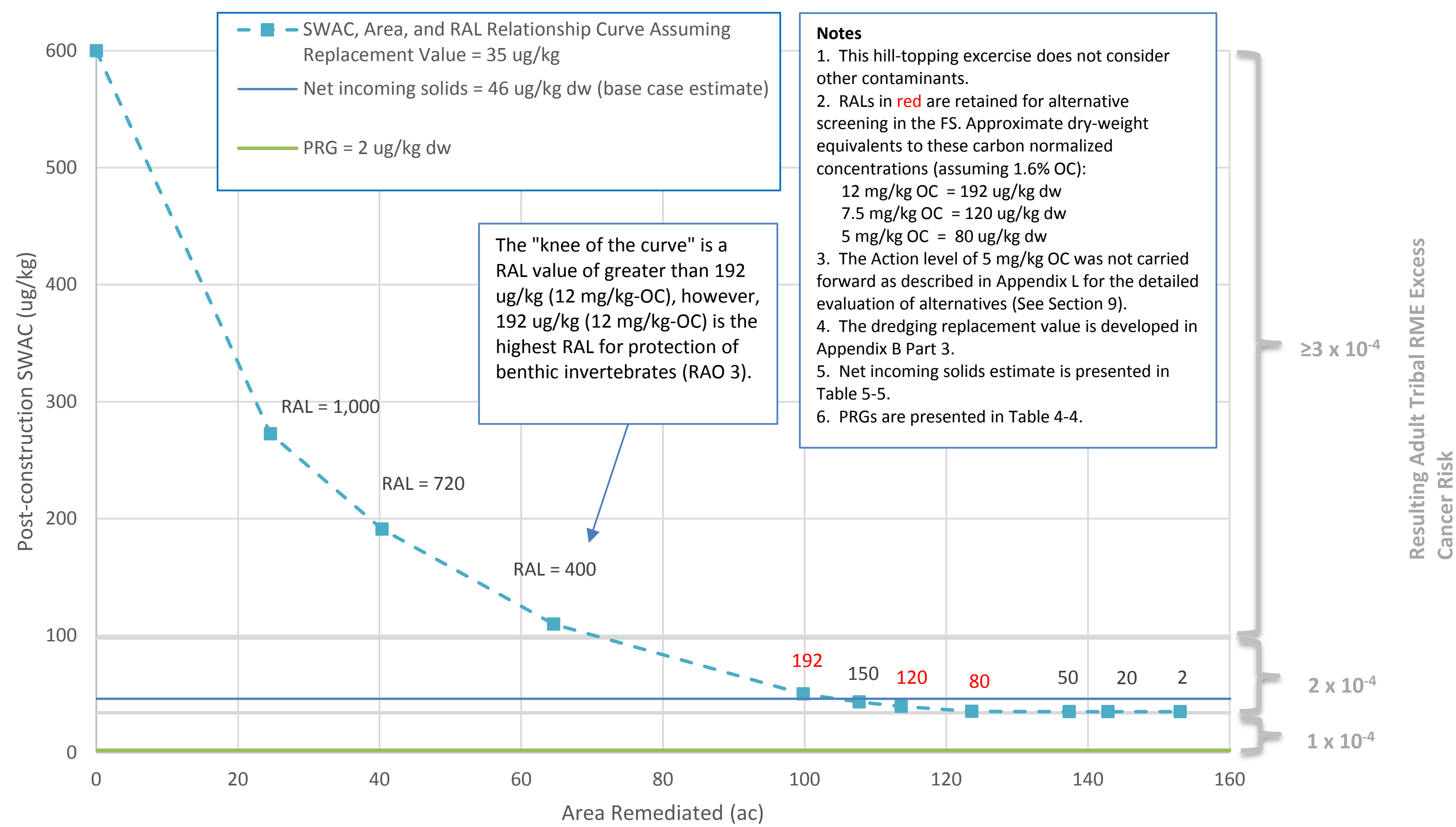


Figure 6-2
PCBs RALs, Remediation Area, and Resulting Post-construction SWACs
Feasibility Study
East Waterway Study Area

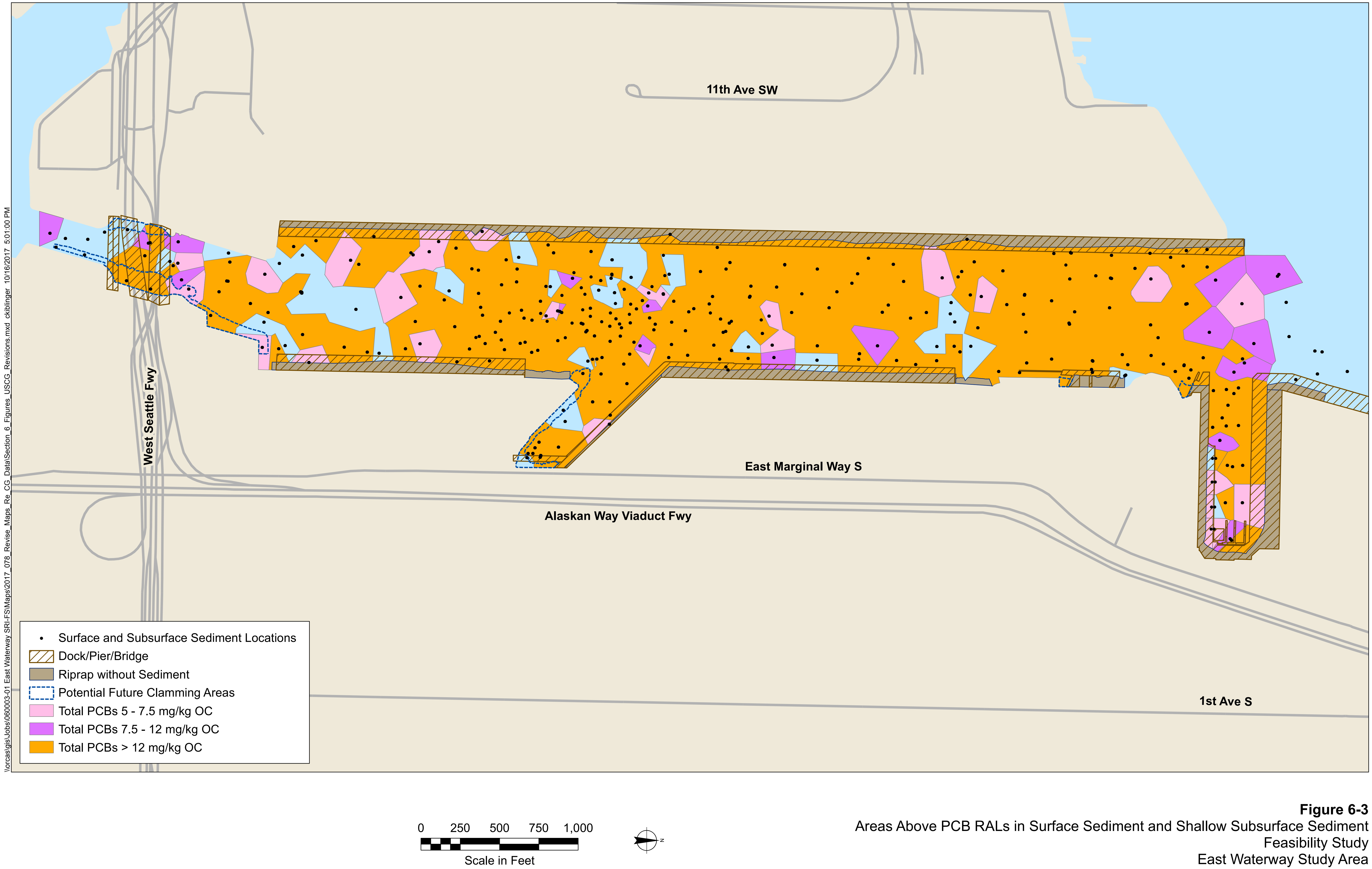
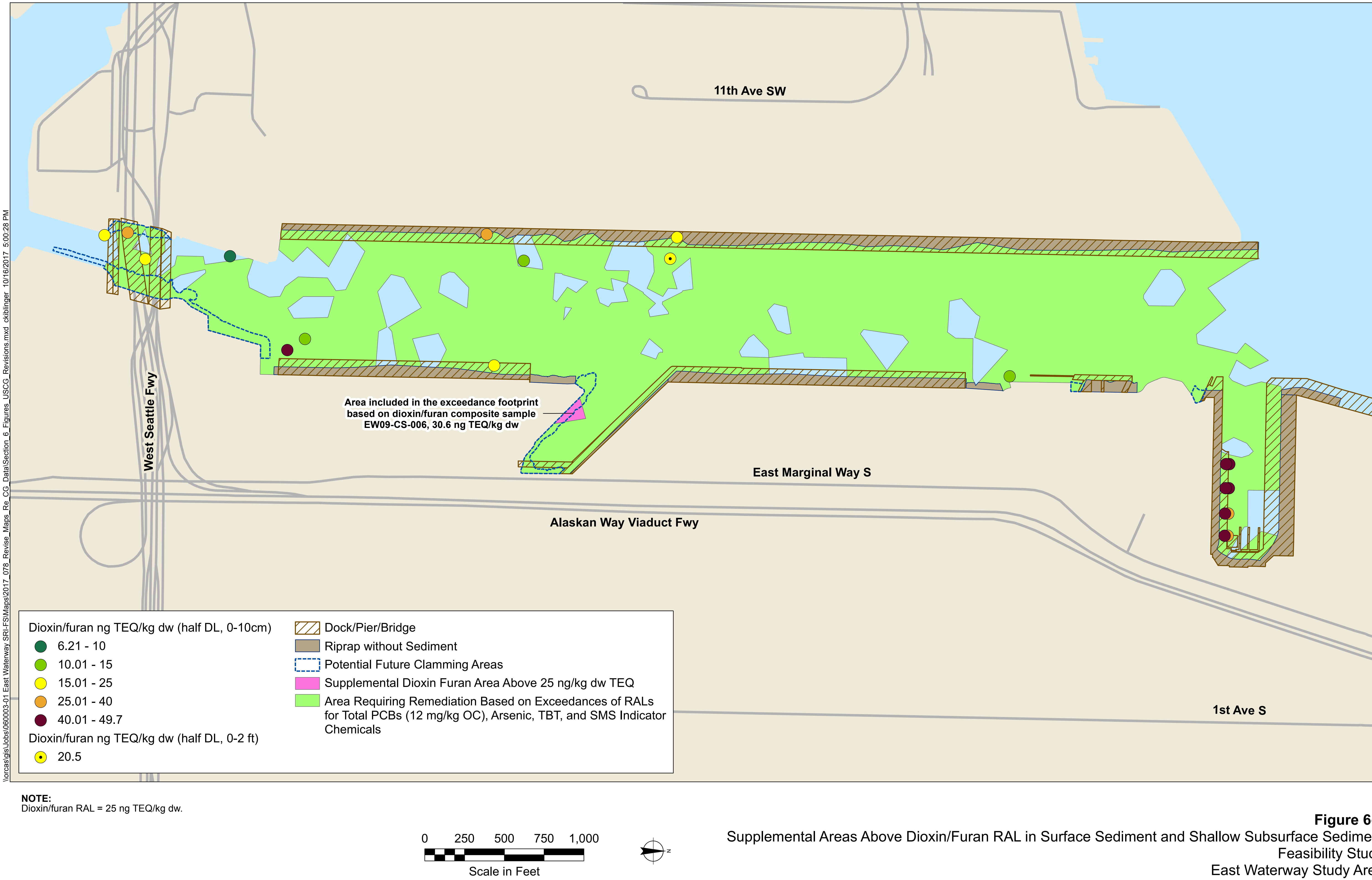
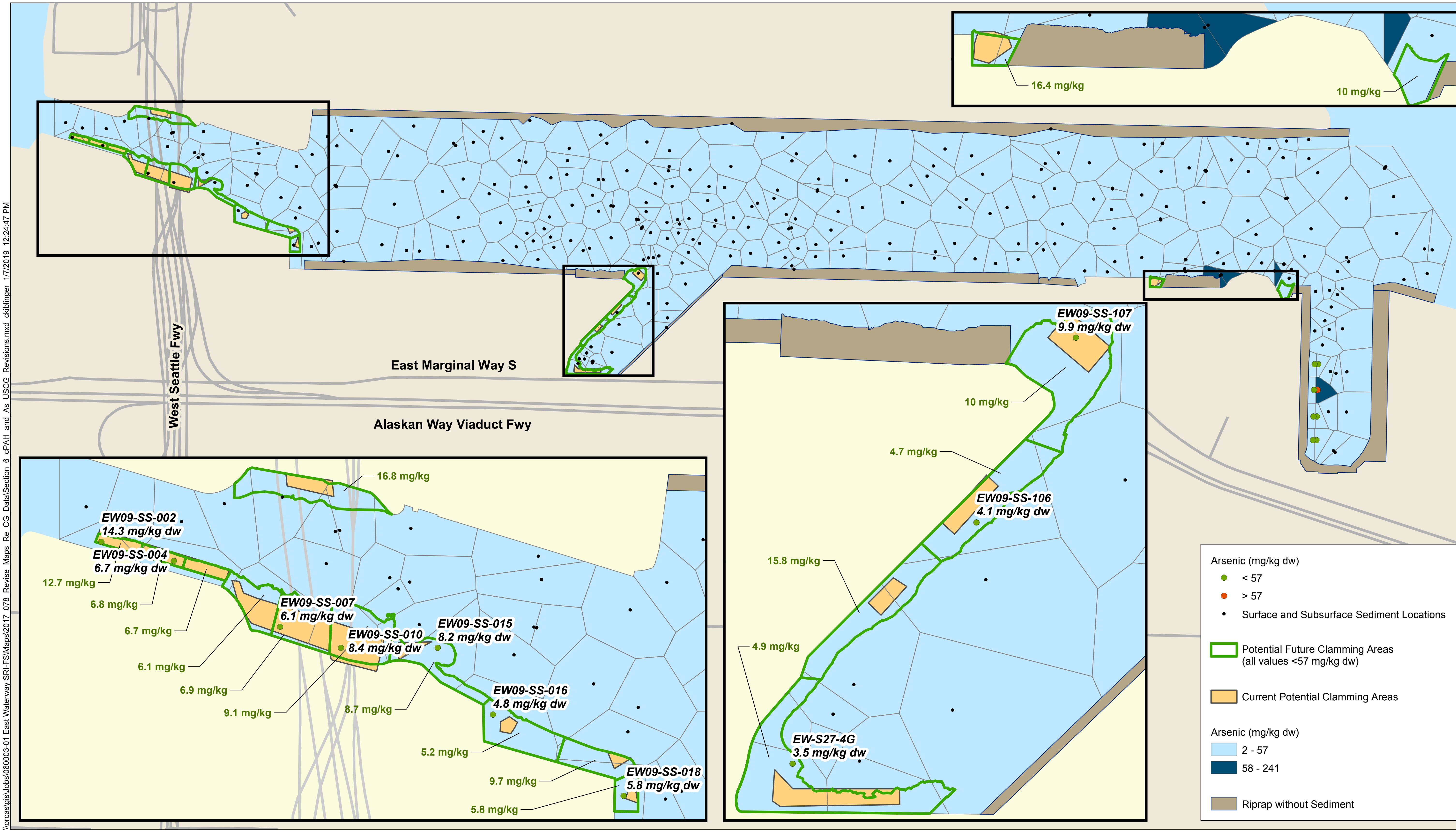


Figure 6-3
Areas Above PCB RALs in Surface Sediment and Shallow Subsurface Sediment
Feasibility Study
East Waterway Study Area



NOTE:
Dioxin/furan RAL = 25 ng TEQ/kg dw.

Figure 6-4
Supplemental Areas Above Dioxin/Furan RAL in Surface Sediment and Shallow Subsurface Sediment
Feasibility Study
East Waterway Study Area



NOTE:
Clamming Area and site-wide Arsenic RAL= 57 mg/kg dw.

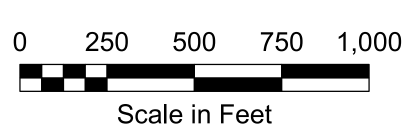
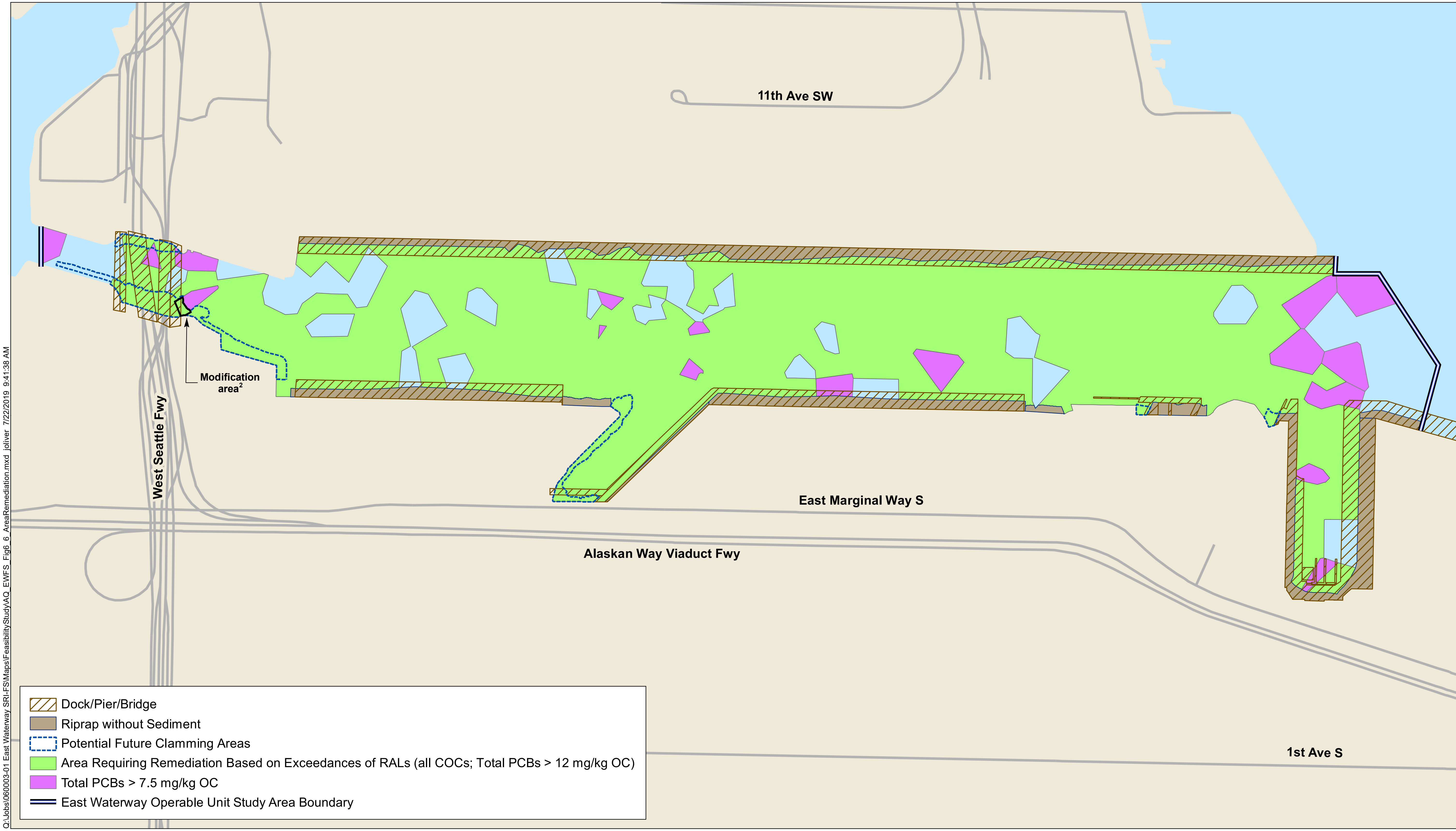


Figure 6-5
Areas Above Site-wide and Intertidal RALs for Arsenic in Surface Sediment and Shallow Subsurface Sediment
Feasibility Study
East Waterway Study Area



NOTES:

1. RAL: Remedial Action Level
2. This 0.11 acre area should technically be shown as part of the dark pink remediation area (Total PCBs > 7.5 mg/kg OC) due to a modification of the benzo(a)pyrene cancer slope factor used for cPAHs that occurred late in development of the FS. For the sake of efficiency, no adjustments were made to the FS from this point forward to reflect this condition because the small areal adjustment has no effect on rounded areas, volumes, and costs. Actual remediation areas will be further delineated with additional sampling during remedial design.

Figure 6-6
Area Requiring Remediation
Feasibility Study
East Waterway Study Area

7 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

This section identifies and screens remedial technologies consistent with EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988). This section incorporates the findings of the technology screening conducted for the EW OU in the Screening Memo (Anchor QEA 2012a), which identified and screened a comprehensive set of general response actions (GRAs), technology types, and process options that are potentially applicable to cleanup of contaminated sediments in the EW OU.

This section and the Screening Memo (Anchor QEA 2012a) incorporate work previously completed as part of the LDW FS for screening technologies (AECOM 2012), which has been reviewed by stakeholders and approved by EPA, and is relevant to the EW based on proximity of the sites to each other, similar site conditions, and similar COCs. Screening and retention of many technologies were based on these documents, and those decisions have generally been included in this FS.

Updates to account for any recent technology developments or relevant experience at other cleanup sites since finalization of the Screening Memo (Anchor QEA 2012a) are included in this section. The Superfund Innovative Technology Evaluation Program, the EPA Hazardous Waste Clean-up Information website, and the Federal Remediation Technologies Roundtable were reviewed for recent and relevant information about innovative treatment technologies, including their cost and performance, results of technology development and demonstration, and technology optimization and evaluation. The site-wide identification and evaluation of remedial technologies have generally not been modified from the Screening Memo, and the results of that evaluation are summarized in Sections 7.2 through 7.5. Points of departure from the Screening Memo are noted in the text. The location-specific (i.e., Construction Management Area-specific) evaluation of remedial technologies have been modified from the Screening Memo based on additional information and further analysis of the site; the results of that analysis are presented in Sections 7.6 through 7.7.

Consistent with EPA guidance (EPA 1988), the technologies are presented in a tiered approach intended to provide layers of specificity that will aid in screening technologies for each GRA, Technology Type, and Process Option:

- **General Response Actions**. GRAs may be used individually or in combination to satisfy EW OU site-specific RAOs. For the EW OU, GRAs include no action, institutional controls, monitored natural recovery, enhanced natural recovery, containment, removal, treatment, and disposal.
- **Technology Type**. The next layer of tiered technologies include the remedial and disposal technologies, which categorize technologies within a GRA to achieve RAOs. For example, within the removal GRA, dredging and dry excavation can be used to accomplish the action.
- **Process Options**. Process options are specific processes within each technology that could be employed to accomplish the site RAOs. These process options are selected to address site-specific conditions and constraints. For example, within the dredging technology type, mechanical dredging or hydraulic dredging can be used.

The Screening Memo (Anchor QEA 2012a) evaluation was conducted using the effectiveness, implementability, and cost criteria consistent with EPA guidance (EPA 1988). Effectiveness refers to whether or not a technology can contain, reduce, or eliminate COCs. Implementability refers to whether a technology can be operated under the physical and chemical conditions of the EW, is commercially available, and has been used on sites similar in scale and scope of the EW.

Key considerations in the screening of technologies in the EW include site-specific constraints from structures, aquatic uses, habitat, and water depth. As first introduced in the Screening Memo (Anchor QEA 2012a), the EW OU has been divided into specific CMAs that represent areas with similar structural conditions, or similar aquatic use, habitat, or water depth conditions. The boundaries of some of the CMAs and description of site characteristics have been updated in this section to reflect additional information acquired since finalization of the Screening Memo.

This section identifies and describes representative, effective, and implementable potential remedial and disposal technologies that are retained for incorporation into remedial alternatives described in Section 8. The discussion of retained technologies considers information on past and current sediment remediation projects in the Puget Sound region, elsewhere in EPA Region 10, and nationally where appropriate. Reducing the number of process options does not preclude reexamination of these options during the remedial design phase of the cleanup project. Rather, it is a means to streamline the development and evaluation of the remedial alternatives without sacrificing engineering flexibility.

Specifically, this section consists of the following components:

- A description of the GRAs, technology types, and process options (Section 7.1)
- A description of each remedial technology and screening decisions (Section 7.2)
- A description of each disposal technology and screening decisions (Section 7.3)
- A description of short- and long-term monitoring that may be required before, during, and after construction of the selected remedial alternatives (Section 7.4)
- A description of ancillary technologies that may be employed in combination with other process options (Section 7.5)
- A summary of the general site conditions affecting remedial technology selection (Section 7.6)
- A description of critical site constraints in the EW affecting the implementability of certain technologies (Section 7.7)
- Evaluation of remedial technologies for CMAs (Section 7.8)

The complete screening process is summarized in tables as follows:

- Table 7-1 (see Section 7.1) lists all of the candidate remedial technologies and process options that were evaluated in the FS process, along with the screening for applicability
- Table 7-2 (see Section 7.6) summarizes general site conditions affecting remedial technology selection
- Table 7-3 (see Section 7.7) provides descriptions of EW OU CMAs based on site restrictions that affect the selection of applicable remedial technologies
- Table 7-4 (see Section 7.8) integrates the critical site constraints information with the retained remedial technologies, to show where each retained technology is applicable within a particular area and which technologies are carried forward in the alternatives analyzed in Section 8.

7.1 Review and Selection of Representative Technologies

In accordance with CERCLA guidance, cleanup technologies are organized under GRAs that represent different conceptual approaches to remediation. These GRAs include the following:

- No Action
- Institutional Controls
- Natural Recovery (including MNR and ENR)
- In situ Containment
- Removal
- In situ Treatment
- Ex situ Treatment
- Disposal

Table 7-1 describes the GRAs, technology types, and process options potentially appropriate to the EW OU sediments, and identifies whether they were screened out or retained for consideration in the FS in the Screening Memo (Anchor QEA 2012a). Each of the retained technologies is discussed in subsequent sections. The screened technologies form the basis for this FS; however, additional information could lead to the reconsideration of eliminated technologies during remedial design. Remedial technologies are described in Section 7.2, and disposal technologies are described in Section 7.3.

7.2 Remedial Technologies

The identification and screening evaluation of potentially applicable remedial and disposal technologies are provided in the sections below.

7.2.1 No Action

No Action is a retained technology as required per CERCLA. No Action will be used as a baseline comparison against other technologies. No Action requires no human intervention but can include long-term monitoring to ensure that there are no long-term unacceptable risks to the environment or human health (EPA 1988). No Action can only be selected where the site poses no unacceptable risks to human health or the environment.

Table 7-1
East Waterway Technology Screening

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Cost	Screening Decision
No Action	None	Required by National Contingency Plan	High	Low	Low	Retained
Institutional Controls	Proprietary Controls	Access and property use restrictions; maintenance agreements	Moderate	Low to Moderate	Low	Retained
	Informational Devices	• Monitoring and notification of waterway users • Seafood consumption advisories, public outreach, and education • Enforcement tools • Environmental Covenants Registry	High	Low	Low	Retained
Natural Recovery	Monitored Natural Recovery	Sedimentation	High	Moderate	Low	Retained
	Enhanced Natural Recovery	Placement of thin layer of clean cover	High	Moderate	Low to Moderate	Retained
In situ Containment	Cap	Conventional Cap	Moderate	High	Moderate	Retained
		Low-permeability Cap	Low	High	Moderate to High	Not Retained
		Reactive Cap	Low	High	Moderate to High	Retained
Removal	Dry Excavation	Excavator	Low	Moderate to High	High	Retained (in limited areas)
	Dredging	Mechanical Dredging	Moderate to High	Moderate to High	High	Retained
		Hydraulic Dredging	Low in Open-water Areas; Low to Moderate in Underpier Areas	Moderate to High	High	Retained for Underpier Areas to the extent practicable; not retained elsewhere
In situ Treatment	Physical-Immobilization	Amendments (e.g., activated carbon, organoclays)	High	Moderate to High	Moderate to High	Retained
		Stabilization	Not retained			
		Electro-chemical Oxidation				
		Vitrification				
		Ground Freezing				
	Biological	Slurry Biodegradation				
		Aerobic Biodegradation				
		Anaerobic Biodegradation				
		Imbiber Beads				
	Chemical	Slurry Oxidation				
		Oxidation				
	Physical-Extractive Processes	Oxidation				
		Sediment Flushing				

Table 7-1
East Waterway Technology Screening

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Cost	Screening Decision
Ex situ Treatment	Physical/Chemical	Acid Extraction	Not retained			
		Solvent Extraction				
		Slurry Oxidation				
		Reduction/Oxidation				
		Dehalogenation				
		Sediment Washing				
		Radiolytic Detoxification				
	Biological	Enhanced Bioremediation				
		Slurry-phase Biological Treatment				
		Fungal Biodegradation				
		Landfarming/Composting				
		Biopiles				
	Physical	Separation	Not retained (may be considered for remedial design)[a]			
		Solar Detoxification	Not retained			
		Solidification				
	Thermal	Incineration				
		High-temperature Thermal Desorption				
		Low-temperature Thermal Desorption				
		Pryolysis				
		Vitrification				
		High-pressure Oxidation				
Disposal	On-site disposal	Confined Aquatic Disposal	Low	Moderate to High	High	Not retained
		Slip 27 NCDF	Low	Moderate to High	High	Not retained
		Slip 36 NCDF	Low	Moderate to High	High	Not retained
	Off-site Disposal	T-5 NCDF	Low	Moderate to High	High	Not retained
		Landfill	High	High	High	Retained
		Open-water Disposal	Low	Low	Low	Not retained
		Beneficial Use	Low	Low	Low	Not retained

Notes:
Shaded cells indicate technologies retained in the Screening Memo (Anchor QEA 2012a).
a. Physical separation was retained in the Screening Memo (Anchor QEA 2012a), but is not retained for developing and comparing remedial alternatives in the FS. Physical separation may be considered in conjunction with other disposal options during remedial design.
NCDF – Nearshore Confined Disposal Facility

7.2.2 Institutional Controls

Institutional controls are non-engineered measures that may be selected as remedial or response actions in combination with engineered remedies, such as administrative and legal controls that minimize the potential for human exposure to contamination by limiting land or resource use (EPA 2000b). The NCP sets forth environmentally beneficial preferences for permanent solutions, complete elimination rather than control of risks, and treatment of principal threats to the extent practicable. Where permanent and/or complete elimination are not practicable, the NCP creates the expectation that EPA will use institutional controls to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants. It states that institutional controls may not be used as a sole remedy unless other measures are determined not to be practicable, based on balancing trade-offs among alternatives (40 CFR 300.430 [a][1][iii]).

EPA recommends that where they may provide greater protection, multiple institutional controls should be used in combination, referred to as "layering." Institutional controls may be an important part of the overall cleanup at a site, whenever contamination is anticipated to remain following remediation at concentrations that exceed cleanup levels. Institutional controls may be applied during remedy implementation to minimize the potential for human exposure (as temporary land use or exposure limitations). These controls may also extend beyond the end of construction (or be created at that time) or even after RAOs are achieved to ensure the long-term protectiveness of remedial actions that leave contaminants on site above cleanup levels (as long-term or permanent limitations, e.g., protecting a contaminant barrier like a sediment cap from being accidentally breached).

Institutional controls potentially applicable to cleanup of the EW OU are identified and discussed below. This section describes specific individual controls in sufficient detail to allow for a comparison of remedial alternatives that include various types and degrees of reliance on institutional controls. An integrated Institutional Controls Implementation Plan for the EW that meets specific location, tribal, and community needs is anticipated after the ROD is issued. These considerations are discussed further in the FS as part of the development and evaluation of remedial alternatives (Sections 8 and 9).

EPA guidance broadly lists four types of institutional controls: governmental controls, proprietary controls, enforcement tools, and informational devices. However, governmental controls such as the permitting of some discharges to the EW or dredging and filling of the EW, as well as some enforcement controls, such as consent decrees or administrative orders under which settling parties implement remedies including institutional controls, are not discussed at depth in this FS because they do not affect the choices among alternative remedies; however, they are included in Table 7-1 for general information. These governmental controls are, for remedy selection purposes, uniform across all alternatives and options, and consent decrees will be used if responsible parties implement any or all of any remedial action that EPA selects in the ROD as required by Section 122(d) of CERCLA. Therefore, the most important institutional controls, or aspects of them, that will be considered for the development of remedial alternatives are emphasized below. Enforcement tools, even though they are used, for example, to establish enforceable proprietary controls pursuant to consent decrees or orders, are discussed under the category of informational devices. It should be clear that many categories overlap and that the agency guidance that created them was intended to be helpful in analyses rather than necessarily invent divisible categories (e.g., proprietary controls have government enforcement mechanisms to ensure their continuation, and some informational devices can be related to or enhanced by governmental enforcement programs):

- Proprietary controls
- Informational devices
    - Monitoring and notification of waterway users
    - Seafood consumption advisories, public outreach, and education
    - Enforcement tools
    - Environmental Covenants Registry

These types of institutional controls are outlined below.

7.2.2.1 Proprietary Controls

Proprietary controls are recorded rights or restrictions placed in property deeds or other documents transferring property interests that restrict or affect the use of property. A covenant is a grant or transfer of contractual rights. An easement is a grant of property rights by an owner, often for a specific purpose (e.g., access, utility, and environmental, among other types of easements). Covenants and easements are essentially legally binding arrangements that allow or restrict usage of property for one or more specific objectives (e.g., habitat protection or protection of human health). They commonly survive the transfer of properties through real estate transactions and are binding on successors in interest who have not participated in their negotiation. This distinguishes covenants and easements from ordinary contracts or transactions between or among parties. At cleanup sites, covenants and easements commonly control or prevent current and future owners from conducting or allowing activity that could result in the release or exposure of buried contamination for as long as necessary. Potential activities controlled or prohibited may include in-water activities (e.g., anchoring, spudding, or vessel or tug maneuvering) and construction activities (e.g., pile driving and pulling, dredging, or filling) where buried contamination may become exposed as a result of the activity, as long as it is an activity that the owner may legally control. Selecting a less expensive remedy in the form of a proprietary control that limits future property uses in ways that a more expensive remedy would not involves a complex balancing of interests by EPA. For example, a proprietary control can lower remedial costs for a former owner at the expense of the redevelopment options of a current owner, who acquired the property after it was contaminated. For this reason, among others, EPA policy and guidance stress assessing reasonably anticipated future land use as an important part of remedy selection generally, and specifically stress limiting use of institutional controls.

In Washington State, Ecology has the right to enforce covenants created under MTCA. More recently, Washington passed its Uniform Environmental Covenants Act (UECA), which allows EPA, as well as the state (in addition to the parties to an UECA covenant), to enforce environmental covenants. For this reason, UECA covenants are anticipated to be the primary proprietary control used in EW environmental cleanup actions, if selected as part of a cleanup remedy.

Parties with sufficient ownership interests in shorelines and aquatic land could grant UECA covenants that would help ensure that remedial measures (such as sediment caps) are not disturbed. However, UECA covenants may not be implementable or practicable for portions of the EW where access and use are difficult to control. Another uniquely important interest to consider is the extent to which public entity-granted covenants may interfere with tribal treaty-protected seafood harvesting, in particular.

7.2.2.2 Informational Devices

Monitoring and Notification of Waterway Users

Notification, monitoring, and reporting programs are an example of an informational device potentially applicable. Under such a program, the protection of areas where contamination remains above levels needed to meet RAOs, including areas where capping has been utilized, could be enhanced.

Such areas could be periodically monitored (by vessels and/or surveillance technology), with vessels performing the dual role of educating potential violators of the existence of activity restrictions and promptly reporting violations of use restrictions to EPA, or USCG if an area within the EW OU were formally designated as a Restricted Navigation Area (RNA) by formal USCG rulemaking as described in Section 7.2.2.3. Notification to waterway users could further be provided through enhanced signage and other forms of public notice, education, and outreach. A mechanism for the review of any USACE navigation dredging plans and other Joint Aquatic Resource Permit Application (JARPA) construction permitting activity could be established. The review would identify any projects that may compromise containment remedies or potentially disturb contamination remaining after remediation, which would include a requirement to promptly notify EPA during the permitting phase of any project that could affect cleanup remedies. This mechanism would serve as a backup to an existing Memorandum of Agreement between EPA and USACE for coordinating such permitting, especially if that agreement were to lapse or be discontinued for any reason by either agency in the future.

Additional measures could include: 1) establishing an EW cleanup protection hotline that private citizens could call or email to report potential violations, with a requirement that reports be investigated and conveyed to EPA (and the USCG for any RNAs) under specified protocols; and 2) developing and implementing periodic seafood consumption surveys to identify, by population group and geographical location, which seafood species are consumed, where they are consumed, and in what quantities they are consumed. This information would be used to update the Institutional Control Implementation and Assurance Plan (ICIAP) as appropriate and improve seafood consumption advisories and associated public outreach and education. Additional monitoring of the effectiveness of these tools can be used to adapt this approach, as discussed in the next section. The effectiveness of all these measures could be re-evaluated periodically to assess which ones should be continued or be modified.

Seafood Consumption Advisories, Public Outreach, and Education

The Washington State Department of Health (WDOH) publishes seafood consumption advisories in Washington. WDOH currently recommends no consumption of resident seafood from the EW. Salmon are not resident in the EW; they are anadromous species that spend most of their lives outside of estuaries like the EW and LDW. WDOH recommendations for EW salmon are the same as for Puget Sound as a whole (e.g., no more than one meal per week of Chinook salmon). WDOH maintains a website that includes its advisories and provides publications and other educational forums that cover healthy eating and seafood consumption. In addition, WDOH seafood consumption advisories are posted on signs at public access locations in the EW. Following these advisories is wholly voluntary, which limits the effectiveness of advisories.

The Washington State Department of Fish and Wildlife (WDFW) develops and enforces seasonal restrictions on recreational fishing and seasonal and daily catch limits per individual for various seafood species. All recreational fishers over 15 years of age must have a fishing license and comply with specific size, species, and seasonal restrictions on fishing for fish and shellfish throughout the Puget Sound region. While WDFW summarizes the WDOH seafood consumption advisories, which may enhance their reach and effectiveness, they do not prohibit fishing or shellfishing within the EW. Under WDFW regulation, it is lawful to seasonally collect certain fish and shellfish from the EW. Concerns associated with the use of these institutional controls include the burden placed on tribes exercising their treaty rights and other fishers who use the EW. Relying on seafood consumption advisories to further reduce human health risks may require fishers to change behavior or make cultural adjustments. This burden is difficult to assess precisely given the broad range of needs different fishers may have.

The application of community-based social marketing concepts (EPA 2009a, 2009b) could be employed in the EW to reduce the limitations of seafood consumption advisories and improve the effectiveness of existing seafood consumption advisories for protecting human health. The overarching goal of these efforts would be to develop and implement a public outreach and education program that focuses on incentives and activities that research indicates have the greatest likelihood of adoption and would make the greatest substantive difference in environmental health. Ideally, the program would be coordinated with other health-based initiatives such as the City of Seattle's urban agriculture initiative.

A significant difference between other community-based social marketing sites and the EW (and the LDW) is the presence of tribal fishing rights in the EW secured by treaties of the United States. Nothing in this section or anywhere in this FS is intended to suggest that exercise of such rights, or the underlying cultural traditions, would be precluded by seafood consumption advisories and related programs to reduce contaminated seafood consumption as part of EW remedial action. For this reason, the seafood consumption advisories and public outreach education programs should be developed in consultation with affected tribes to develop accommodations for such tribes to the greatest extent practicable.

7.2.2.3 Enforcement Tools

RNAs are a form of notification program that are created by the promulgation of formal rules by the USCG. RNAs represent an enforceable means of protecting containment remedies and other areas where contamination remains from anchoring and other physical interference, particularly where UECA covenants or other proprietary controls may not be achievable. To the extent that RNAs may potentially interfere with seafood harvest activities, particularly tribal harvests, engineered or alternate means of accommodating fish harvest should be devised (e.g., alternative means of allowing anchoring or tying off a net within a RNA-created no-anchor zone). Although this option has the significant potential to regulate potential impacts associated with anchorage, barge spudding, and tugboat propeller wash, it could restrict maritime commerce or preclude commercial activities generally necessary for construction, maintenance, and operation of commercial piers, depending on where the RNA was located. Like proprietary controls in general, even for sediment areas in private ownership, RNAs require a careful and often highly complex balancing of competing interests and may only be useful in certain locations or circumstances.

7.2.2.4 Environmental Covenants Registry

Placement and maintenance of EW areas with containment remedies, or anywhere where contamination remains above levels needed to meet RAOs, on Ecology's Environmental Covenants Registry in its Integrated Site Information System would provide information regarding applicable restrictions (RNAs and proprietary controls) to anyone who uses or consults the state registry.

7.2.2.5 Institutional Controls Summary

In summary, it must be emphasized that all of the institutional controls, where necessary, are an important component of a remedy. However, enforcement of institutional controls requires monitoring. Privately owned sediments, like publically owned sediments, in an urban commercial waterway are more difficult to guard or restrict uses of than upland properties. Further, it is anticipated that some people, will choose to fish and consume what they catch regardless of fishing regulations, seafood consumption advisories, and robust public outreach and education programs.

7.2.3 Monitored Natural Recovery

Natural recovery is the process by which contaminant concentrations in sediment are reduced through a combination of physical, biological, and chemical processes so that surface sediment concentrations are reduced to acceptable levels within a specified timeframe. Natural recovery includes physical processes (e.g., sedimentation, advection, diffusion, dilution, dispersion, bioturbation, and volatilization), biological processes (e.g., biodegradation, biotransformation, phytoremediation, and biological stabilization), and chemical processes (e.g., oxidation/reduction, sorption, or other processes resulting in stabilization or reduced bioavailability) (EPA 2005). Physical processes act to either bury surface sediment with newly deposited sediments or mix surficial sediment with deeper subsurface sediments through bioturbation, propwash, or other mixing influences. Biological processes can be effective at degrading certain organic compounds, reducing mass or toxicity. Chemical processes, such as absorption of organic chemicals to carbon sources, also may assist with natural recovery.

MNR relies on the natural recovery processes described above and also includes monitoring to ensure that natural recovery is occurring as predicted. MNR differs from long-term monitoring because MNR includes monitoring in specific locations to meet specific target concentrations, and long-term monitoring is used to assess waterway conditions without specific target concentrations. MNR includes adaptive management to determine whether additional remedial actions are necessary. MNR has been approved for remedial actions on many contaminated sediment sites and is considered administratively implementable.

MNR has been shown to be effective at reducing sediment concentrations in CERCLA sites within the Puget Sound, such as Bremerton Naval Complex (AECOM 2012), underpier areas of Sitcum Waterway, Commencement Bay, Tacoma (Patmont et al. 2004), and other portions of the Commencement Bay site in Tacoma (EPA 1989), and Bellingham Bay (Patmont et al. 2004). MNR alone is unlikely to be effective in the majority of the EW OU due to the high degree of vessel usage present. While some areas may receive sediment deposition that lowers surface sediment concentrations over time and contributes to natural recovery processes, the presence of mixing from propwash in the navigation channel and berthing areas is considered to be a significant factor that would reduce the effectiveness of MNR in the EW. The deeper mixing that can occur from propwash would extend the time to reach acceptable concentrations, potentially to unreasonable timeframes (Section 5).

Other factors that affect MNR include chemical and biological processes. While chemical process, such as absorption to organic chemicals to carbon sources, may assist with natural recovery, biological processes are typically not effective at significantly reducing PCB and metals within a reasonable recovery timeframe (EPA and USACE 2000). As discussed in the Screening Memo (Anchor QEA 2012a), MNR alone would likely have relatively low effectiveness in achieving the RAOs. However, MNR may potentially be effective in localized areas as a component of an alternative with combined remedial technologies—particularly in areas that are net depositional and without deep mixing from propwash. Regardless of whether MNR is selected as a remedial technology in the alternatives, natural recovery processes are an important component to be included in the effectiveness evaluation for each remedial alternative presented in Section 9.

MNR is retained as a potential remedial technology with the above-noted limitations. It has been demonstrated in sediment remediation projects and will be carried forward in developing EW remedial alternatives.

7.2.4 Enhanced Natural Recovery

ENR, while a form of natural recovery, involves placement of a layer of clean material over sediment with relatively low to moderate contaminant concentration levels to expedite the natural recovery process. With ENR, the natural recovery process is accelerated as clean material is mixed with the underlying contaminants from bioturbation or vessel propwash (EPA 2005). As described in EPA (2005), ENR can quickly reduce exposure to contaminants and typically requires less infrastructure than ex situ technologies (e.g., dewatering, treatment, and disposal). ENR placement is intended to speed up burial processes and is not intended to provide complete containment of the underlying contaminated sediments. Monitoring is a component of ENR to document that predicted natural recovery is occurring or to determine whether additional remedial action may be required if ENR does not occur as predicted. ENR is typically performed with clean sand material of low OC content for constructability reasons; however, monitoring information from the EW Phase 1 Removal Action (Windward 2007b, 2008a, 2008b), from other sites in the Duwamish (e.g., Duwamish Diagonal Capping and ENR Areas [AECOM 2012], and the Slip 4 Early Action Area [Integral 2015]) demonstrate that sediments equilibrate to ambient OC concentrations within 1 year due to accumulation of incoming sediment (including OC), benthic recolonization, and biological activity (see Appendix B, Part 5).

In the EW, ENR is technically implementable, as supported by the use of predictive modeling discussed in Section 5, to determine areas where natural processes support the use of natural recovery, enhanced with clean cover placement. Placement of ENR clean cover material can be accomplished using readily available equipment options in all CMAs. ENR placement in most underpier CMAs would be more difficult due to equipment inaccessibility and steep underpier side slopes, impacting the stability of the sand layer. ENR has been approved for remedial actions on many contaminated sediment sites and is considered administratively implementable.

ENR has been shown to be effective at reducing sediment concentrations in CERCLA sites within the Puget Sound, such as Commencement Bay (Tacoma, Washington), Eagle Harbor (Bainbridge Island, Washington), Puget Sound Naval Shipyard (Kitsap County, Washington), and at the Ketchikan Pulp site (Ketchikan, Alaska) (Thompson et al. 2003). Within the EW, ENR could be considered for areas of relatively low to moderate contaminant concentrations that are net depositional or in areas where engineered capping (discussed in Section 7.2.5) would be difficult to implement. ENR's effectiveness may be limited in certain CMAs due to vessel propwash, which could cause significant re-suspension and mixing in areas with frequent vessel usage (e.g., propwash zones 1A, 1B, 2, 4A, and 6 in Figure 5-2). ENR's overall effectiveness is considered to be moderate relative to other remediation technologies due to the greater degree of uncertainty about its performance. During design, the use of engineered aggregate mixes or engineered synthetic products may be considered to ensure stability in specific areas where propwash is a concern, depending on the selected areas where this technology could be employed.

The ENR costs are considered to be low to moderate since this technology involves careful placement of clean cover material, along with monitoring and, potentially, long-term maintenance needs, should monitoring indicate the need to replenish the ENR layer.

For the EW, two types of thin sand cover have been retained for potential application, depending on the purpose and location. These cover layers are described below:

- ENR employed in the Sill Reach (ENR-sill) refers to the placement of sand to increase the rate of natural recovery through natural processes, including burial. For the FS, the ENR-sill layer is assumed to consist of an average placement of 9 inches of sand (6 inches minimum placement), consistent with typical thickness assumptions at other sites, and the hydrodynamics and operational considerations of the location; this area has no vessel traffic and a low scour potential, and the thin layer of sand is expected to undergo biological mixing but not undergo significant resuspension and lateral transport over the long term.
- ENR employed in the navigation channel and adjacent berthing areas (ENR-nav) refers to placement of a thin layer of material designed to accelerate natural recovery and to mitigate the effects of resuspension from vessel scour. For the FS, ENR-nav is assumed to have an average thickness of 18 inches (15 inches minimum) to decrease

the contribution of shallow subsurface contamination on concentrations in the biologically active zone in areas anticipated to have deep sediment mixing.

Section 5.4 describes the principles of mixing and long-term modeling simulations following placement of ENR-sill and ENR-nav. Consistent with these modeling assumptions, the ENR layer is expected to partially mix with underlying sediment. This is in contrast to an isolation cap (Section 7.2.5), which is designed to fully isolate sediments.

While specific assumptions have been developed for use in this FS, the composition of ENR material will depend on location-specific factors evaluated during remedial design. For example, the composition and thickness of ENR placement material may be modified to mitigate scour (e.g., grain size specifications or thickness) or enhance habitat (e.g., habitat mix).

ENR is retained as a potential remedial technology with the above-noted limitations. It has been demonstrated in sediment remediation projects and will be carried forward in developing EW remedial alternatives.

7.2.5 In situ Containment (Capping)

In situ containment refers to the placement of an engineered subaqueous covering or cap of clean material on top of contaminated sediment that will remain in place. A cap would be designed to effectively contain and isolate contaminated sediments from the biologically active surface zone. As described in EPA (2005), in situ caps can quickly reduce exposure to contaminants and typically require less infrastructure than ex situ technologies (e.g., dewatering, treatment, and disposal). Because capping leaves contaminated sediments in place, monitoring is a component of in situ containment to ensure that the cap is stable (i.e., not eroding) and continues to effectively isolate contaminants or sufficiently attenuate contaminant mobility through the cap (EPA 2005).

7.2.5.1 Cap Design

Detailed guidance manuals for in situ containment for contaminated sediments have been developed by USACE and EPA (Palermo et al. 1998a, 1998b). The required minimum cap thickness is based on the physical and chemical characteristics of the contaminated sediments and capping material, groundwater flow rates (i.e., advection), erosion potential from natural or anthropogenic sources (e.g., propwash), potential for bioturbation of the cap from aquatic organisms, potential for consolidation of the cap and underlying sediments (including porewater migration that could occur due to compaction), and operations considerations (Palermo et al. 1998a). Total thickness can include cap layers for bioturbation, habitat, consolidation, erosion, operational considerations, and chemical isolation.

A typical cap thickness of up to 3 feet of clean material has been used at many sites (EPA 2005). However, the EW experiences erosive forces from propwash effects from large container ships and tugboats that use the waterway, which necessitates cap armoring in areas that experience significant propwash forces. For the FS, a conceptual cap thickness of 5 feet is assumed in the EW, consisting of a nominal 2.5-foot chemical isolation layer, 1-foot filter layer, and 1.5-foot armor layer. The surface layer of caps in intertidal areas are expected to contain suitable substrate to support benthic organisms and fish communities. The cap thickness was determined based on propwash and contaminant transport modeling, and is expected to have a design life of more than 100 years (Appendix D). The general cap thickness of 5 feet is appropriate for the FS; however, cap thickness will be determined during remedial design and may be thicker or thinner depending on location-specific considerations and additional analysis.

Appendix D demonstrates the predicted effectiveness of the 2.5-foot isolation layer by modeling the movement of contaminants through the cap from underlying sediments with a one-dimensional groundwater flux model (Lampert and Reible 2009). The analysis showed that PCB breakthrough above the assumed performance goals is not expected to occur in less than 100 years following construction. The analysis also showed that cPAHs behave similarly to PCBs and, therefore, would not exceed similar performance goals. Some minimum OC requirements may be required for cap materials to achieve a cap design life of more than 100 years. Specific areas with high metals concentration (e.g., mercury) may also need to be evaluated during remedial design to address the potential for dissolved metals to migrate through a proposed cap to surface sediment and surface water. Cap material specification would be evaluated during remedial design.

Reactive capping is a technology that typically includes addition of sorptive capacity of the cap, depending on the type of contaminant present, to reduce the flux of contaminants from underlying sediments to shallow porewater and the water column. Use of reactive materials may also be warranted where evaluations of standard capping indicate that a sufficiently thick cap cannot be created to adequately reduce the flux of contaminants over time, which may be due to a variety of reasons singly or in combination, such as the presence of highly mobile contaminants, high rates of groundwater advection, and/or the need to maintain certain water depths for navigation or habitat purposes. As described in EPA (2005), examples of materials used in reactive caps include engineered clay aggregate materials and other reactive/adsorptive materials, such as AC. One example was at the 2012 early action at Slip 4 in the LDW, where AC was incorporated into the sand and gravel chemical isolation layer of the cap and placed with a mechanical clamshell (Schuchardt et al. 2012). Reactive agents (e.g., apatite, AC, and/or organoclay) may also be placed within geotextile layers on the sediment surface as a reactive mat. Reactive mats will be considered as a potential option during remedial design. To date, caps with reactive layers have tended to be used in areas with higher underlying sediment concentrations of highly mobile contaminants. Section 7.2.7.1 provides additional discussion of these principles with respect to in situ treatment through the placement of AC.

7.2.5.2 Cap Material Placement

Capping placement can be accomplished using a number of mechanical and hydraulic methods. Placing sand- and gravel-sized materials in a controlled fashion can be accomplished with a variety of equipment such as:

- Controlled discharge from hopper barges
- Hydraulic pipeline delivery of a sand slurry through a floating spreader box or submerged diffuser
- Physical dispersion of barge stockpile capping materials by dozing, clamming, conveyoring, or hydraulic spraying of stockpiled material off the barge and into the water column
- Mechanically fed tremie tube to contain lateral spread of the cap material until it reaches the bottom of the water column
- Lowering of individual, reactive mat cap segments with a crane or other mechanical equipment

Sand and gravel placement can often be accomplished in more difficult access areas through the use of conveyors or hydraulic pipeline discharge. However, steep side slopes are a critical limitation to cap placement due to the ability of cap material to be placed and stay stable on steep slopes. Placement of an armor layer made of cobbles or rocks is more complicated than sand and gravel placement and requires a greater degree of operator skill to avoid overplacing the rock armor layer or prevent missing areas of required armoring. The placement equipment for rock is typically limited to mechanical equipment since hydraulic pipelines and conveyors are limited as to the size of materials they can effectively transport. Rock placement is also limited on steep slopes. In addition, the installation of reactive mat caps in underpier areas would face multiple technical challenges, including access limitations for construction equipment, need for anchoring on riprap slopes, presence of debris, potential need for armoring due to propwash, and the presence of piles that could result in incomplete mat coverage.

Most of the EW is unrestricted open water, and it is feasible to place an engineered cap in waterway areas that do not have overwater piers. For the underpier CMAs, capping material likely is infeasible to place due to equipment inaccessibility, structural and slope stability impacts from placing added weight, and likely infeasibility of placing a stable cap on steep underpier side slopes, which have been designed to approximate 1.75 horizontal to 1 vertical (1.75H:1V) for Port facilities and 2H:1V for USCG piers. As a comparison, temporary stable slopes for sand and gravel mix underwater are generally limited to slopes of 3H:1V or flatter, or 2.75H:1V or flatter, with careful placement (based on experience, also: NavFac [1986]). For the Sill Reach CMA, capping may be difficult to place due to access issues underneath the existing bridge structures. However, the Sill Reach does not have the steep slopes that are present at the Underpier CMAs.

7.2.5.3 Elevation Requirements

In many areas of the EW, capping would also require some dredging because of the need to maintain federally authorized navigation depths and operational berthing depths. CMAs within the federal navigation channel, berth areas, Slip 27, and Slip 36 have minimum water depths that would need to be maintained. Figure 7-2 shows the authorized and operational navigation elevations in the EW.[84]

In such cases, the final elevation of the top of the placed cap would be below the maintained federal navigation channel elevation or berth operational elevations. In some cases, this may require some dredging to accommodate the maximum cap thickness to avoid overplacing the cap above the channel bottom or berth minimum elevations. The cap elevation requirements and associated extent of dredging will be determined during remedial design, which would also consider cap thickness requirements (as described in Section 7.2.5.1). This FS assumes that the top of a sediment cap would be 4 feet below the maintenance elevation in the navigation channel, which accounts for overdredge, vertical accuracy of the dredge, and an additional buffer for safety. In addition, it is assumed that caps that border the navigation channel will have appropriate buffers to avoid being damaged by maintenance dredging activities. These buffers will be reviewed and discussed with USACE during remedial design stages considering site-specific uses and dredging methodology, authorized channel elevations, and existing operational elevations.

Intertidal and nearshore habitats may be home to diverse communities of fish, birds, mammals, and invertebrate species. Therefore, areas with depths shallower than -10 feet MLLW will be managed in ways that approximately restore current elevations. In these areas, partial dredging would be required prior to cap placement to restore the location to pre-construction conditions.

The FS assumes that source material for isolation capping will be imported from commercial off-site vendors. A possible alternative material sourcing could be dredged materials from Puget Sound maintenance dredging sites. Challenges to beneficial use of this material include the following:

[84] As discussed in Section 2.9.2, USACE completed a draft SHNIP Feasibility Report and Environmental Assessment in August 2016, which includes alternatives for deepening and widening the navigation channel. Because the implementation of the navigation improvement project is uncertain, the assumptions for remedial technologies (e.g., post-capping elevation requirements) are based on current conditions and uses. However, all proposed caps within the EW are also compatible with potential future navigation improvements.

- Determining the suitability of material gradation and contaminant concentrations to meet the defined cap material specifications
- Coordinating contract requirements with the federally procured USACE dredge contract
- Adjusting to mismatched production rates (e.g., maintenance dredged material may be generated at rates much less than, or far exceeding, cap placement rates)
- Accounting for re-handling needs and/or lack of suitable storage for dredged material awaiting beneficial use
- Coordination and timing of projects

7.2.5.4 Summary

Capping is considered an effective remedial technology for all COCs in the EW, especially for highly sorbed contaminants such as PCBs. Capping has been shown to be a reliable and proven technology that has been effective at many CERCLA sites within the Puget Sound, such as Commencement Bay (Tacoma, Washington), Eagle Harbor (Bainbridge Island, Washington), Pacific Sound Resources (Seattle, Washington), Georgia-Pacific Log Pond (Bellingham, Washington), and throughout the United States. Because cap construction can be conducted with relatively little disturbance to in situ contaminated sediment compared to dredging, this technology is considered to have relatively few environmental impacts during construction (partial dredging and capping disturbs more in situ contaminated sediment than capping alone). However, capping buries the existing benthic community, which takes time to recolonize and regain ecological functions following construction, and may require habitat enhancement material in addition to cap material to encourage return of the biota.

Capping is considered a moderate cost technology due to the expense of the materials, installation (especially in complex, multiple-layer caps), and monitoring and maintenance requirements. Capping is retained as a potential remedial technology with the above-noted limitations. It has been demonstrated in sediment remediation projects and will be carried forward in developing EW remedial alternatives.

Although small areas of the EW OU may be capped without preliminary partial dredging and still comply with the elevation constraints described above, most of the EW OU would require partial dredging prior to capping and, therefore, capping is referred to as "partial dredging and capping" in subsequent sections of this FS.

7.2.6 Removal

Mechanical dredging, hydraulic dredging, and excavation using upland-based equipment (dry excavation) are the three representative process options available for removal technologies. Removal may result in the least uncertainty regarding future environmental exposure to contaminants because the contaminants are removed from the aquatic ecosystem and disposed in a controlled environment (EPA 2005), but can: 1) result in release of contaminants (i.e., dissolved or sorbed to suspended sediment particles), which in turn results in short-term water quality impacts from dredging that can increase fish and shellfish tissue concentrations both locally and downcurrent (tidal direction) (Bridges et al. 2010); and 2) disturb the benthic community that must recolonize the biologically active zone and regain ecological functions following remediation. Removal is readily applicable in areas with navigation depth requirements because it does not require material placement (as opposed to capping). However, site restrictions and existing structures can limit the ability to remove all contaminated sediment within the waterway. Removal has been proven to be an effective technology for achieving cleanup goals when used in combination with residuals management[85] (see Section 7.2.6.5) and other BMPs (see Section 7.5.3).

This section discusses the mechanical dredging, hydraulic dredging, and dry excavation process options, as well as dredging considerations in underpier areas and dredge residuals management. Removal requires handling of dredged or excavated sediment, including dewatering, offloading, transport, treatment (if required), and disposal, each of which involves additional costs and the potential for further releases. The full process of removal is often referred to as the "treatment or process train." Sections 7.2.7 and 7.3 discuss treatment technologies and disposal options, respectively.

[85] Residuals management includes placement of a thin clean sediment cover over the dredge residuals as a final step in the remediation process to achieve cleanup levels on the sediment surface post-construction.

7.2.6.1 Mechanical Dredging

Mechanical dredges have been used extensively in the Puget Sound for sediment remediation projects and are widely available. Mechanical dredges are designed to remove sediment at or near in situ density (EPA 2005), though some amount of excess water is typically entrained in the dredge bucket as it closes and is lifted up through the water column. The quantity of water generated using mechanical dredging is orders of magnitude less than that generated with hydraulic dredging. The barge-mounted or land-based crane can use different types of buckets or attachments to dredge or assist with demolition activities. Mechanical dredges are capable of working in difficult-to-access areas and are relatively easy to relocate, thus reducing the potential impact to existing site operations. Environmental buckets can be used in the appropriate sediment conditions to help limit sediment resuspension during bucket retrieval (see Section 7.5.3.1).

A typical "treatment or process train" for mechanical dredging (assuming landfill disposal) assumed for this FS is listed below:

- Dredge contaminated sediment
- Place contaminated sediment in a haul barge
- Dewater on the barge (treatment by filtering or any active measures to meet water quality criteria at the point of compliance)
- Transport contaminated sediment to either an on-site or off-site offloading/staging area
- Offload sediment to a stockpile area
- Treat effluent from the stockpile and discharge to receiving waters or approved publically owned treatment works (POTW)
- Transport contaminated sediment over land by truck or rail
- Dispose contaminated sediment at a landfill facility

Mechanical dredging is considered feasible for open-water areas because of its effective removal of consolidated sediment, debris, and other materials such as piling and riprap and its ability to relocate, thus reducing the potential impact to existing site operations. In underpier areas, mechanical dredging would be infeasible due to equipment inaccessibility.

Some applications of mechanical dredging in shallow water environments have been performed with increased positional control over the dredge bucket when using a fixed arm (as opposed to a cable arm). This method has been employed at the Plant 2 Early Action Area in the LDW. However, this method would only be applicable for nearshore areas in the EW OU, and not the majority of the waterway due to deep water depths.

7.2.6.2 Hydraulic Dredging

Hydraulic dredging typically involves using a cutterhead or similar equipment to slurry sediment in the water column and siphon the slurry into a pipe. Hydraulically dredged material can be transported via piping directly to a staging/processing area. The hydraulic transport pipeline is typically a floating pipeline, which can interfere with vessel navigation. Relative to mechanical dredging, a significantly greater volume of water is entrained with the sediment slurry removed by the dredge and must be subsequently separated from the sediment solids and treated and discharged (EPA 2005). The solids content of hydraulically dredged slurries typically averages about 10% by weight, but it can vary considerably with the specific gravity, grain size, and distribution of the sediment, and depth and thickness of the dredge cut. In general, hydraulic dredges cannot remove rocks and debris. Hydraulic dredging has been implemented at many contaminated sediment sites, although hydraulic dredging has been used much less frequently than mechanical dredging at sediment remediation sites in Puget Sound.

Dewatering of hydraulically dredged sediments is required prior to upland transport and disposal. Hydraulically dredged sediments can be dewatered using passive or active methods and typically requires use of large settling basins due to the relatively large volume of water in the resulting slurry collected. Dewatering requires an upland staging area, usually in close proximity to the dredge area due to the difficulties in placing, operating, and maintaining long distances of pipeline over water and land. The EW OU has limited space in the upland area close to the EW that is not already under a long-term lease. Hydraulic dredging has been retained only for underpier areas.

7.2.6.3 Underpier Dredging

Removing contaminated sediment from underpier locations presents significant engineering and construction challenges. Dredging must be accomplished working around existing structures. However, removals require coordination with the owner. Riprap slopes are often constructed in underpier areas to provide slope stabilization or wave and propwash protection purposes, and contaminated sediment fills in the interstices of the riprap, making it impossible to remove all of the contaminated sediment using dredging methods.

The feasibility of underpier dredging is dependent upon the pier design (e.g., pile spacing, deck elevation, and other obstructions), presence of debris and broken-off piling, underpier slope geotechnical conditions, and ability of equipment to access the underpier area without potentially damaging the existing structure. Few examples of diver-assisted hydraulic dredging are available that removed contaminated sediment located under piers on smaller projects (e.g., Esquimalt Graving Dock, Victoria, British Columbia, 2013-2014; Sitcum Waterway Remediation, Tacoma, Washington, 1995). However, diver-assisted dredging has significant issues including extremely low production rates, inability to remove consolidated sediment, inability to remove debris, and safety concerns. Specifically, the risks for injury and death during construction increase with every hour divers would need to be assisting hydraulic dredge activities. This risk is weighed against long-term risk of leaving contaminated sediment in the underpier areas (Section 9.1). Underpier hydraulic dredging has the same considerations as standard hydraulic dredging, such as use of a hydraulic pipeline, extensive water management needs, and the need to dewater the sediment, but with significant additional technical and safety challenges. Diver-assisted hydraulic dredging is retained for further consideration in underpier areas, despite the drawbacks discussed above. Design criteria would be developed during the design phase if this technology is selected.

In summary, the site conditions for underpier diver-assisted hydraulic dredging include the following:

- Sediment removal from steep slopes (1.75H:1V in most areas) composed of large riprap and difficult-to-reach interstices.

- Work conducted in deep water, limiting dive time for each diver and potentially requiring the use of decompression chambers (as required by commercial diving regulations), resulting in a large team of divers to complete the work and making the work more hazardous from a worker health and safety perspective.
- Low visibility because of shade from the pier, water depth, and sediments suspended as part of the work, making the work more hazardous from a worker health and safety perspective.
- Debris, such as cables, large wood, and broken pilings, making dredging more difficult and potentially more unsafe.
- Presence of infrastructure, such as existing piling and cross bracing, which will require relocation of both floating and submerged lines into and out of each row of piles.
- Generation of large quantities of water that must be treated prior to discharge back to the waterway. Upland areas are not typically available for slurry storage, sediment settling, effluent treatment, testing, and discharge because of Port operations at existing terminals, and pipeline transport of the slurry to an upland staging location is not feasible because of the interference with navigation. Therefore, it is most likely that the sediment slurry will need to be handled using a portable treatment system on a barge, which complicates the water containment, dewatering, and treatment, and could limit the daily production rate.
- Underpier areas adjacent to active berthing areas, which average around 300 container ships per year and 600 total vessel calls per year in the EW. Diving schedules are likely to be significantly impacted by waterway activities, which could result in delays in completing the work. In particular, dive time may be further limited due to risks posed to divers from propwash and suction forces from transiting and berthing container ships. Similarly, more business interruption will occur as a result of hydraulic dredging because of restricted access to areas where divers are performing underwater work.

Mechanical underpier dredging is not retained for further consideration because it may pose unacceptable risks for damaging the existing structures or underpier riprap slopes and environmental concerns associated with sediment resuspension as a result of dragging sediment from the underpier area downslope into the toe of slope where additional equipment can be used to re-dredge the sediment and lift it to a haul barge.

7.2.6.4 Dry Excavation

Sediment excavation involves the use of excavators, backhoes, and other conventional earth-moving equipment to remove contaminated sediment from exposed sediment areas (e.g., not submerged). This is particularly pertinent in portions of the EW where equipment could conduct dry excavation in shoreline or intertidal areas during low tide.

Dry excavation can also be conducted by diverting or draining water. Diversion of water from the excavation area can be facilitated through the installation of temporary cofferdams, sheetpiling, or other water management structures and the subsequent lowering of the surface water elevation within the excavation area. Following dewatering of the area, equipment can be positioned on the bed within the excavation area or immediately adjacent to the dewatered excavation area. Diversion tends to be generally limited to localized areas with high sediment concentrations. These temporary structures could disturb buried subsurface contamination and could result in releases when removed. During remedial design, engineering evaluations would be conducted to determine appropriate methods of diverting water in areas where this process option is necessary and feasible.

7.2.6.5 Dredge Residuals

All dredging projects result in some degree of re-suspension, release, and residuals (NRC 2007). Dredging residuals include undisturbed residuals (or missed inventory), which is contaminated sediment that remains un-dredged due to the inability to be 100% accurate in delineating all of the contaminated sediment. The quantity of missed inventory can be minimized through sampling conducted as part of remedial design. Residuals also includes generated residuals, which are contaminated sediment re-suspended during dredging, due to removal equipment limitations in preventing loss of particulate and dissolved material. The particulate material that settles is the generated residuals. The need to address dredging residual contamination depends upon the concentrations and thicknesses of residuals remaining. However, empirical data from numerous sediment remediation projects indicate that residual contamination is a common occurrence and that sites are unlikely to achieve their RAOs with dredge technology alone (Patmont and Palermo 2007; NRC 2007).

Research has shown that residual sediment remaining on the post-dredge surface (typically ranging from 2% to 11% of the remaining contaminated sediment mass prior to the final production dredge pass) have been observed during most environmental dredging projects (Desrosiers and Patmont 2009). The relatively deep water depths in the EW increase the likelihood of generating dredge residuals, which could spread to adjacent unremediated areas as a result of vessel propwash, since remediation would be conducted in an active waterway over multiple construction seasons.

Common approaches to managing dredging residuals are discussed in detail in Appendix B, Part 5. The final residuals management approach decision framework will be developed during remedial design. Once the residuals management decision framework is developed, post-dredging monitoring data will be used to determine if and what residuals management contingency actions are needed to meet the dredging performance goals. Residuals management contingency actions may include natural recovery, placement of RMC, or re-dredging.

RMC refers to the placement of approximately 4 to 12 inches of sand following dredging, to reduce the impact of dredging residuals on surface sediment concentrations, as needed, in open-water dredging areas (see Section 7.2.6.5). RMC, like ENR, is generally assumed to mix with shallow subsurface sediment and incoming sediment as a result of bioturbation and vessel propwash in scour areas. Recent sediment remediation project designs include placing a residuals cover as either the primary or secondary residuals management technology (e.g., LDW Slip 4 Early Action Area, East Waterway Phase 1 Removal Action, Port of Olympia Berths 2 and 3 Interim Action, Port Gamble Wood Waste Removal, and Denny Way Interim Action). Placement of RMC may be limited by site conditions, such as inability to place on steep slopes. The physical placement of RMC could resuspend and disperse fine-grained residuals. RMC is typically used as a contingency action if post-remediation surface sediment concentrations exceed a set threshold; the need, extent, and thickness of the RMC would be determined following post-removal sampling. Similar to ENR, RMC is typically performed with clean sand material of low OC content for constructability reasons. As discussed in

Section 7.2.4 and Appendix B, Part 5, sediments are expected to equilibrate to ambient OC concentrations within 1 year due to accumulation of incoming sediment (including OC), benthic recolonization, and biological activity.

As discussed in Appendix B, Part 5, RMC is considered a cost-effective method for achieving post-dredging performance goals, and is therefore likely to be used in the EW following dredging. For this FS, it has been conservatively assumed for costing purposes that RMC will be placed in all open-water dredged areas and in areas adjacent to dredged areas where dredge residuals may be redistributed and result in elevated concentrations (i.e., interior unremediated areas). RMC would be placed by spraying, by a spreader, or by spreader barge with a conveyor and sand box, similar to placement of ENR.

7.2.6.6 Summary

Dredging is a proven and reliable remedial technology and suitable for use in the EW when used in combination with residuals management. Dredging does result in release of contaminants (i.e., dissolved or sorbed to suspended sediment particles) to the water column during construction, and potential sediment transport will likely result in water quality impacts during dredging even if all dredging BMPs are used.

For the FS, mechanical dredging is retained in all areas except under piers. Hydraulic dredging is retained in underpier areas, but has significant safety issues as well as design and construction issues due to technical feasibility, water management issues, equipment (i.e., floating pipeline), and impacts to navigation. Dry excavation may be employed in shoreline areas, including the Sill Reach, subject to further evaluation during design. Dredging near structures may need to be restricted to avoid adversely impacting their stability. Dredging may also be used in conjunction with capping to meet elevation restrictions.

7.2.7 Treatment Technologies

Treatment technologies refer to chemical, physical, and biological process options that can be applied to contaminated sediment, either in situ or ex situ, to reduce concentrations, immobilize the contaminants, or reduce bioavailability of contaminants to biota. Treatment technologies have been reviewed as part of the LDW RI/FS and included in the LDW memo

(RETEC 2005), as well as in Tetra Tech (2010). These previous treatment evaluations were presented in the Screening Memo (Anchor QEA 2012a) and have been accepted by EPA Region 10, and are relevant to the EW based on proximity of the sites to each other, similar site conditions, and similar COCs. This section presents in situ and ex situ treatment technologies retained for consideration in the FS.

7.2.7.1 In Situ Treatment

In situ sediment treatment technologies include sequestering agents (e.g., AC), biological or chemical degradation, immobilization, and other potentially appropriate treatment technologies to reduce levels or mobility of sediment contaminants while leaving sediments in place. For the EW, sediment amendments have been retained for further consideration. EPA has recently supported in situ application of amendments as an in situ treatment and is overseeing a pilot study on the use of AC in the LDW. AC has been demonstrated to reduce the bioavailability of several contaminants, including PAHs, PCBs, dioxins/furans, DDT, and mercury, when directly mixed into sediment (EPA 2011; Ghosh et al. 2011). AC has been added as an amendment to both sand cover and bentonite (Cornelissen et al. 2011a; Oen and Cornelissen 2010; Oen et al. 2011). Another type of amendment used as an in situ treatment includes addition of organoclay to reduce the bioavailability for non-soluble organics and potentially other contaminants (Sarkar et al. 2000). This type of in situ treatment is most applicable to sediment in the biologically active zone (i.e., approximately the upper 10 cm of sediment). A different form of in situ remediation, in situ bio-enhancement, is a technology that is being explored by researchers but has not been retained in this FS.

Considering the range of COCs identified in EW, in situ sediment treatment is a potential remedial technology. Recent data from Bremerton Naval Shipyard indicate that in situ treatment can reduce bioavailability of PCBs in Puget Sound sediments (Chadwick et al. 2014). Patmont (2013) identified 19 sites worldwide where AC or biochar materials have been used for the in situ treatment of contaminated sediments. The AC process option has been demonstrated to be effective in the short term (limited long-term data are available) for organic contaminants at several remediation project sites including the Grasse River in Massena, New York (Ghosh 2010; Alcoa 2010), Hunter's Point Naval Shipyard in San Francisco, California (Luthy et al. 2009; Cho et al. 2009; Janssen et al. 2009, 2011), Aberdeen

Proving Ground in Maryland (Menzie 2011a, 2011b), U.S. Army Installation in Virginia (Menzie 2011a, 2011b), and at several sites in Norway (Oen and Cornelissen 2010; Oen et al. 2011). Successful AC placement has occurred at these sites using rotary tilling, injection, broadcasting, and with a “tine sled” device that directly injected AC into near-surface sediment. At the sites in Norway, pre-mixing AC with another medium (e.g., sand) prior to placement was found to accelerate the natural bioturbation process, resulting in a more homogeneous long-term application of AC when placed in shallow water depths or in the “dry” (Oen and Cornelissen 2010; Oen et al. 2011).

Since AC is a low density, lightweight material, it is typically blended with other traditional sediment materials such as silts, sands, or dredged material from nearby waterways to generate a material that will sink to the bottom of the area to be treated. Several proprietary products have been developed that combine the AC with a heavier core particle and other binding agents to produce a particulate material that can be placed like a soil or sediment. Examples of the latter material include Sedimite™ and AquaGate+PAC™.

The design life of specific amendments would be evaluated during remedial design, and will vary based on the targeted contaminants, source and type of amendment, amount of amendment used (i.e., design safety factor), and the potential need for replenishment. Physical stability and chemical activity (e.g., adsorption capacity) over the long term are the most important design life factors. AC and other charcoals created under high-temperature conditions are known to persist for thousands of years in soils and sediments, and laboratory studies and modeling evaluation both indicate promising long-term physical stability of the amendment material and chemical permanence of the remedy (Ghosh et al. 2011).

Underpier areas are identified for in situ treatment under some remedial alternatives to reduce bioavailability. Location-specific factors will be evaluated during remedial design, especially related to type and amount of the amendment and habitat considerations.

In situ Treatment Effectiveness Assumptions

For the purpose of modeling, this FS estimates that in situ treatment will reduce bioavailability of total PCBs, cPAHs, and dioxins/furans by 70%. This is on the low end of values measured in the field and laboratory when applying an AC dose between 3% and 5%.

EPA (2013) concluded that, "...adsorption of hydrophobic organic contaminants (HOCs) to AC in sediments is often 10 to 100 times greater than absorption to organic carbon (OC)," indicating a percent reduction between 90% and 99%. A bioavailability reduction of 70% has been selected for these EW site conditions in coordination with EPA, considering EW-specific conditions, including the potential for burial, mixing, and loss of AC material from propwash forces.

Recent field pilot studies indicate that a 70% reduction in bioavailability is at the low end of measured values for PCBs and other hydrophobic contaminants. Chadwick et al. (2014) found that total PCB concentrations in underpier areas at the Bremerton Naval Shipyard decreased by 90% in porewater and 80% in bioaccumulation test organisms in nine sample stations 10 months following application of AC. Beckingham and Ghosh (2011) found that bioaccumulation of PCBs in worms was reduced between 69% and 99%, and concentrations in porewater were reduced by greater than 93% in 3 years following AC amendment of river sediments. A pilot study in Trondheim Harbor also indicated that approximately 90% reduction in bioavailability can be achieved for PCBs and PAHs with variations based on the matrix of delivery (i.e., AC with sand versus AC with clay versus only AC; Cornelissen et al. 2011b).

Review of laboratory studies also indicates that 70% reduction in bioavailability is at the low end of measured values for PCBs and other hydrophobic contaminants. Ghosh et al. (2011) summarized a number of laboratory demonstrations, concluding that laboratory "...tests with a range of field sediments showed that AC amendment in the range of 1-5% reduces equilibrium porewater concentration of total PCBs, PAHs, DDT, and dioxins/furans in the range of 70% to 99%, thus reducing the driving force for the diffusive flux of hydrophobic organic compounds into the water column and transfer into organisms."

Based on these studies, this FS estimates that an appropriate in situ treatment material could be selected and engineered to reduce bioavailability of PCBs by 70% in underpier sediments of the EW, which is approximately in the low end of the range of empirical studies and at the low range of EPA guidance (EPA 2013). While any hydrophobic organic contaminant that comes into contact with in situ treatment material is expected to very quickly result in reduction of bioavailability, the low end of the range was selected due to frequent vessel traffic and high propwash forces in the EW, which could result in the resuspension and distribution of AC material and therefore reduce effectiveness. However, in situ treatment is an evolving remedial technology with new information available every year. Bioavailability assumptions may be refined based on additional data that may soon become available, such as additional monitoring data from the underpier in situ treatment area at the Bremerton Naval Shipyard, which may be pertinent to EW evaluations.

Underpier Material Placement

Access to the sediments in underpier areas would be difficult, due the presence of the supporting piles and the low overhead clearance under the pier deck surfaces. The use of traditional marine-based dredging or barge-mounted placement equipment is precluded due to these access restrictions. Since the primary in situ treatment technology being considered for use in the EW relies on the placement of particulate material containing AC, these access restrictions will determine the methods for placement.

All of the available AC-containing materials fundamentally require the handling of a bulk material from a stockpile and subsequent placement at the required amount per surface area on the sediments to be treated. Methods for moving these materials into confined places such as the underpier areas may be limited to specialized equipment and placement methods, such as long-reach conveyors like a Telebelt™ system and hydraulic or pneumatic pumping and placement. The FS assumes that selection of a remedial technology for placement of in situ treatment will occur during remedial design; for costing purposes, the FS assumes use of a Telebelt conveyor. Each of these methods are briefly described below.

Telebelt™ – The Telebelt is a telescopic belt conveyor that has been used at sediment remediation sites (e.g., Bremerton Naval Shipyard) for the placement of a variety of capping and AC treatment materials. The systems are truck-mounted or trailered, can be placed on a barge, and can extend to reach up to 200 feet, depending on the ability to properly deploy the outrigger system and the weight of the materials to be conveyed. When used to place AC amendment, the system can be placed on a barge alongside the pier being remediated. The conveyor can be extended horizontally under the pier between each row of pilings. The conveyor speed is regulated along with the arm movement to place a known amount of material over the target area.

Hydraulic Pumping – In the hydraulic pumping method, the AC-containing materials are mixed with site water to form a slurry that can be pumped to the sediment area to be treated. When used in an underpier setting, divers are most often used to control the discharge lines and place the material. This system allows for control of the material placement and coverage thickness, but is labor intensive and is a slow process. The slurried material is also susceptible to flowing down any slopes, more so than a granular material being placed through the water column. The slurrying process can also introduce difficulties in maintaining a consistent AC dosage when a blended material is being used due to separation during mixing and placement, although many sites have overcome these potential difficulties.

Pneumatic Pumping – Materials such as the Sedimite™ product have a low enough density that they have been successfully placed using pneumatic blower systems. These applications have primarily been in wetland situations where backpack-mounted blowers are used to place relatively small volumes of material. In an underpier application, a pneumatic system potentially could be used to deliver a similar type of product using divers or personnel in small boats operating in the inter-piling areas to control the discharge end of the pump line. Placement with this method would be considered a slow process, and a granular material that is light enough to move pneumatically may not settle quickly and efficiently through a deeper water column.

Ex situ Treatment

Ex situ treatment refers to technologies that immobilize, transform, or destroy COCs after first removing contaminated sediment from the site. For the EW, the separation, or soil washing, ex situ treatment process option has been retained for further consideration. This option uses conventional and readily available material handling unit processes to separate sediment particles, typically into coarse (sand and gravel) and fines (silt and clay) fractions. These equipment systems include screening, gravity settling, flotation, and hydraulic classification (e.g., using hydrocyclones) (USACE-DOER 2000). Soil washing is a wet process and therefore, generates wastewater that requires treatment and discharge. Depending on site conditions, the washed coarse fraction may be suitable for in-water placement (see Section 7.3.3 for beneficial uses of sediment) as a cap, ENR, or habitat creation/restoration medium. However, the treated sediment to be used as placement material would be subject to physical and chemical testing to confirm suitability in meeting the specification requirements (material gradation and chemical concentrations) for use at the site, and therefore, be accepted as "clean" material. The fines fraction, which has higher concentrations of contaminants, is typically dewatered, transported, and disposed of in a permitted upland landfill. Ideally, the net outcome of soil washing is a reusable coarse fraction and a reduced volume of contaminated material requiring additional treatment or direct disposal.

A small percentage of sediments in portions of the EW may be sufficiently coarse-grained to consider soil washing as a potentially viable treatment. One vendor has indicated that soil washing has the potential to be economical where the sediment contains greater than 30% sand (Boskalis-Dolman 2006). When the sediment contains less than 30% sand, treatment performance and economics deteriorate. Ex situ treatment by soil washing was retained for evaluation in the Screening Memo (Anchor QEA 2012a); however, ex situ treatment is not carried forward as part of the remedial alternatives in this FS. Soil washing has been eliminated from consideration at other recent sites (LDW Record of Decision [EPA 2014]). It could also be part of any of the remedial alternatives presented in Section 8 and would not affect the effectiveness of in-water remediation. Additional evaluation may be considered during remedial design to assess whether adding this ex situ treatment process option to the overall removal "treatment or process train" helps to reduce overall remediation costs.

7.2.7.2 Summary

In situ treatment, specifically the placement of amendments such as AC, has been retained for evaluation in the development of alternatives. None of the ex situ treatment options have been retained.

7.3 Preliminary Disposal Technologies

Several disposal options for dredged sediment were identified in the Screening Memo (Anchor QEA 2012a) and are summarized here for applicability for cleanup in the EW, including confined aquatic disposal (CAD), nearshore confined disposal facilities (NCDFs), upland disposal sites, beneficial use of SMS-suitable dredged material, upland commercial landfill options, and disposal of sediments at the DMMP open-water disposal site in Elliott Bay.

Each of these disposal technologies was evaluated in the Screening Memo for implementability, effectiveness, and cost (Anchor QEA 2012a). Based on that evaluation, only upland landfill disposal was determined to be a viable disposal technology for consideration in the FS. However, each of the disposal technologies listed here are summarized below in the event that specific implementability or effectiveness considerations change that could make them viable disposal options during the remedial design period.

Off-site disposal of dredged sediment from a CERCLA site must be consistent with the Off-Site Rule (40 CFR 200.440). The purpose of the Off-Site Rule is to avoid having CERCLA wastes from response actions authorized or funded under CERCLA contribute to present or future environmental problems by directing these wastes to disposal areas determined to be environmentally sound. It requires that CERCLA wastes may only be placed in a facility operating in compliance with RCRA or other applicable federal or state requirements. The Off-Site Rule establishes the criteria and procedures for determining whether facilities are acceptable for the receipt of CERCLA wastes from response actions authorized or funded under CERCLA. For disposal options discussed in this section, any sediment taken outside of the EW OU study boundary for disposal purposes must comply with the Off-Site Rule. Each of the off-site disposal technologies, including off-site CAD, NCDF, and upland landfill, are expected to be reviewed by EPA in the context of this rule. As discussed in the Workplan (Anchor and Windward 2007), off-site aquatic disposal technologies are evaluated within the general bounds of the Duwamish River, EW, WW, and Elliott Bay.

7.3.1 Aquatic Disposal

7.3.1.1 Confined Aquatic Disposal

CAD is a type of underwater sediment disposal that includes some form of lateral confinement (e.g., placement in natural or excavated bottom depressions or behind constructed berms) to minimize spread of the materials on the bottom. A cap of clean material is used to isolate the marine environment from the contaminated sediment and prevent contaminant mobility through the cap.

A potential CAD alternative within the EW was not retained because a number of considerations and limitations make it logistically challenging and likely technically and administratively infeasible. These considerations include the presence of an active waterway with frequent ship traffic, a federally authorized navigation channel, the communication cable crossing in the vicinity of Station 1700, geotechnical stability to support a CAD site, and structural considerations that limit the extents of the CAD site along the east and west sides of the waterway.

In addition to the on-site CAD option, off-site CAD options have been evaluated as part of the Multi-User Disposal Site (MUDS) program (USACE et al. 1999) and LDW FS (AECOM 2012). A number of CAD sites have been constructed in Puget Sound, including one constructed in 1984 in the WW (Sumeri 1984, 1989; USACE 1994), which was demonstrated to effectively isolate contaminated sediment (USACE et al. 1999).

Use of an off-site CAD site is considered to have significant administrative implementability challenges from the standpoints of siting, constructing, and maintaining a CAD facility. Challenges include obtaining agreement from the landowner(s), monitoring and maintenance needs, and enforcing institutional controls on activities above and adjacent to the CAD site (e.g., restricting anchoring and limiting navigation). Land within the EW and surrounding waterbodies may be state-owned and managed by DNR. DNR policy states that it will not allow any contaminated sediment to be placed on state-owned land.

Due to the difficulties in implementation, the CAD disposal technology is not retained for further consideration in alternative development in the FS. However, a CAD disposal technology may be reconsidered during remedial design if the adverse implementability considerations change.

7.3.1.2 Nearshore Confined Disposal Facility

A NCDF consists of berms, cofferdams, or similar structures that create a contained disposal area for dredged materials. NCDFs provide for permanent storage of dredged sediments. Containment of contaminated sediments in NCDFs is generally viewed as a cost-effective remedial technology at Superfund sites (EPA 1996). NCDFs have been constructed throughout Puget Sound, including in the Milwaukee Waterway in Tacoma, the Eagle Harbor East Operable Unit in Winslow, T-90/91 in Elliott Bay, Pier 1-3 in Everett, and Slip 1 in the Blair Waterway in Tacoma. Within the EW, Slip 27 and Slip 36 have previously been evaluated for the use of this technology.

As part of the EW Deepening Project in 2000 (Anchor 2000), the options of using Slip 27 and Slip 36 as NCDFs were evaluated. Each alternative consisted of using the entire capacity of either slip by constructing a containment berm (closure dike) across the mouth of the slip. Development of Slip 27 as a NCDF would require demolition of existing Pier 28, and development of Slip 36 as a NCDF would require demolition of existing USCG and Port structures, including existing timber and concrete piles, timber and concrete apron, and timber fender piles along Pier 36, the Pier 36 apron, and Pier 37. Contaminated dredged sediment would then be placed within the confined slip up to elevation +9.0 feet MLLW to keep the contaminated sediment at or below groundwater level, which would help to reduce leaching of the contaminants, and a sand cap would be placed to elevation +16.0 feet MLLW.

Off-site NCDF locations were considered within Elliott Bay as part of the MUDS program, and only one conceptual site using the northern shoreline of T-5 was identified and evaluated. Similar to CAD options evaluated in Elliott Bay, no further evaluations of NCDF options have occurred as part of the MUDS program. However, as part of the EW Deepening Project in 2000 (Anchor 2000), the option of using T-5 as a NCDF was re-evaluated. The footprint of this conceptual NCDF is located within the Lockheed West Superfund Site and consists of construction of a three-sided containment berm extending out from the existing shoreline, placement of the project's dredged sediments unsuitable for open-water disposal, and placement of capping materials. The conceptual design would accommodate a storage capacity of 320,000 cy of unsuitable sediment. The T-5 CDF concept was also intended to provide intertidal habitat on the cap surface.

The estimated capacity of the Slip 27, Slip 36, and T-5 NCDFs would be less than the conceptual total volume of contaminated sediment within EW. Many administrative implementability issues are associated with NCDFs, including the presence of state-owned aquatic land at part of each location. DNR owns most of the aquatic lands in the EW and has a policy against placing contaminated sediment on Washington aquatic lands. For Slip 27, another major impediment is a previous agreement developed between the Port and the Muckleshoot Tribe in which the Port agreed to provide a conservation easement that no future pier or moorage improvements will be constructed along the south shoreline of Slip 27 (Muckleshoot Indian Tribe and Port of Seattle 2006). In order to use Slip 36 as a NCDF, USCG facilities would need to be relocated and the land acquired from the federal government. In addition, the EW is a Tribal U&A fishing area, including both slips. Creating a NCDF within the EW would impact U&A fishing and approval may be difficult to obtain. NCDF is therefore not retained for further consideration in this FS.

7.3.1.3 Open-water Disposal

Open-water disposal consists of disposal of sediments at the DMMP unconfined, open-water disposal site in Elliott Bay. This disposal technology would require approval from the DMMP agencies, which include EPA. To be suitable for open-water disposal, sediment must meet screening criteria that is based on chemistry, bioassay, and bioaccumulation testing. It is anticipated that all or nearly all of the sediments required to be removed from the EW because of sediment contamination will not be suitable for open-water disposal. Open-water disposal is not retained for detailed analysis in the FS; however, open-water disposal may be reconsidered during remedial design if there are portions of the EW that are determined to be suitable for DMMP open-water disposal.

7.3.2 Upland Disposal

Dredged sediment can be disposed of off-site at an upland waste disposal facility. Dredged material that satisfies the solid waste regulations could be disposed of in Subtitle D RCRA commercial landfills. Sediments removed from the EW are not expected to require disposal in a landfill permitted to receive RCRA hazardous waste or Toxic Substances Control Act (TSCA) waste (i.e., Subtitle C landfill). The Roosevelt Regional Landfill is operated by Allied Waste in Roosevelt, Washington; the Columbia Ridge Landfill is operated by Waste Management near Arlington, Oregon; and the Weyerhaeuser Landfill at Castle Rock, Washington, are three upland regional landfills that have established services to receive wet sediments. Both have the ability to receive wet dredged sediments delivered to the landfill by rail. One additional landfill, the Greater Wenatchee Regional Landfill in Wenatchee, Washington, requires that the sediment be dewatered so that it will pass the paint filter test for free water prior to accepting the sediment. Disposal at this landfill requires dewatering of sediments for both transport and disposal of the dredged material, which would require a dewatering facility at the point where wet sediments are offloaded from the haul barge to shore. Landfills may elect to use sediment as daily landfill cover; however, this is not considered "beneficial use" because the sediment still requires transport to and tipping at the landfill.

Each of these Subtitle D landfills are retained as representative disposal process options for remedial alternatives that call for sediment removal with disposal in an upland landfill.

7.3.3 Beneficial Use

Beneficial use includes in-water and upland placement of dredged material. Aquatic placement includes use of the sediment as capping material, residual management, or habitat creation. Upland beneficial use could potentially include using the untreated or treated sediment as fill, composting it, or blending it with other humic materials, and selling it as a commercial soil mixture. The physical properties of the treated material may limit its applicability to some of these potential use options.

Beneficial use is technically implementable at the EW, but would only apply to untreated or treated sediment that is below unrestricted state cleanup levels or open-water disposal criteria, which is generally accepted to be "clean" sediment. No EW sediments dredged during cleanup are expected to be below criteria that would allow beneficial reuse as fill material unless treated. In addition, sediment removed from within a CERCLA site is generally not suitable for direct beneficial use applications because of the liability associated with using contaminated material.

For contaminated sediments dredged as part of a cleanup action, treatment would be required before possible beneficial use. The coarser (sand) product (processed material achieving target levels established for the project) from a soil washing process could potentially be reused within the EW for capping, habitat or wetland restoration, or grade restoration (i.e., to meet final bathymetry requirements) as part of the remedial action. However, a review of existing literature and local knowledge did not identify any examples of treated sediments being beneficially used in the Puget Sound region.

The sand produced from a soil washing process could also be reused in the uplands as construction fill or as material feedstock for other industrial or manufacturing applications (e.g., concrete or asphalt manufacture, or compost). Depending on the end use and associated exposure potential, it is not known whether the treated sand fraction would achieve appropriate chemical criteria for all contaminants. Upland beneficial use would also require resolution of legal issues related to material classification, antidegradation, and potential liability. In-water and upland beneficial use is not retained for detailed analysis in the FS; however, beneficial use may be reconsidered during remedial design if there are portions of the EW that are determined to be suitable in the future.

7.4 Monitoring

Monitoring is an important assessment and evaluation tool for collecting data and is a requirement of remedial alternatives conducted under CERCLA. Monitoring data are collected and used to assess the completeness of remedy implementation, remedy effectiveness, and the need for contingency actions. The sampling and testing process options considered at most sediment remediation projects include one or more of the following:

- Sediment quality (e.g., chemistry, grain size distribution)
- Sediment toxicity
- Surface water quality (e.g., conventional parameters and contaminant concentrations)
- Contaminant concentrations in porewater
- Contaminant concentrations in fish and shellfish tissue
- Physical (e.g., visual inspections and bathymetry)

Typically, these sampling and testing process options are prescribed components of project monitoring plans which, in turn, focus on different aspects of the remedial action. For example, monitoring during the construction phase has different objectives than the operation and maintenance (O&M) monitoring that follows construction. Five different monitoring concepts that form the basis for individual or combined monitoring plans, depending on project-specific circumstances, are described below. Appendix G provides the rationale and conceptual structure for a multi-component EW OU monitoring program.

7.4.1 Pre-construction Baseline Monitoring

Baseline monitoring establishes a statistical basis for comparing physical and chemical site conditions prior to, during, and after completion of a cleanup action. Baseline monitoring for the EW could entail the sampling and analysis of sediment, surface water, or tissue samples in accordance with a sampling design that enables such a statistical comparison of conditions.

7.4.2 Construction Monitoring

Construction monitoring during construction activities is area-specific and short-term and is used to evaluate whether the project is being constructed in accordance with plans and specifications (i.e., performance of contractor, equipment, and environmental controls). This type of monitoring evaluates water quality in the vicinity of the construction operations to determine whether contaminant re-suspension and dispersion are adequately controlled. Further, bathymetric monitoring data establish actual dredge prisms or the placement location and thickness of cap material.

7.4.3 Confirmational Sampling

Confirmational sampling is performed at the conclusion of in-water construction and evaluates post-construction sediment conditions. Both chemical and physical data are collected to determine whether the work complies with project specifications.

7.4.4 Operations and Maintenance Monitoring

O&M monitoring refers to data collection for the purpose of tracking the technology performance, long-term effectiveness, and stability of individual sediment cleanup areas. In capping areas, O&M monitoring typically consists of analysis including COCs, grain size, TOC, and cap thickness using sediment or porewater matrices. A combination of tools, including bathymetry soundings, surface grab samples, sediment cores, diver surveys, peepers, staking, and/or settlement plates is used to evaluate cap performance. Some of these tools are also used for ENR and MNR performance monitoring.

7.4.5 Long-term Monitoring

Long-term monitoring evaluates sediment, tissue, or water quality at the site for an extended period following the remedial action to assess risk reduction and progress toward achievement of RAOs. Data collected under long-term monitoring yields information reflecting the combined actions of sediment remediation and source control.

7.4.6 Monitoring Summary

Monitoring is an essential element of remedial alternatives developed in this FS. Appendix G sets forth key assumptions and an overall framework for monitoring using the process options and monitoring objectives described above.

7.5 Ancillary Technologies

Ancillary technologies include dewatering, wastewater treatment, and BMPs. These technologies offer important considerations in the assembly of remedial alternatives.

7.5.1 Dewatering

After removal, dredged sediment may be managed in a number of ways as discussed in Section 7.3. Prior to re-handling, transport, ex situ treatment, or disposal, the dredged sediment may require dewatering to reduce the sediment water content. Dewatering technologies may be used to reduce the amount of water in dredged sediment and to prepare the sediment for on-site consolidation or upland transport and off-site disposal. Further, the dewatering effluent may need to be treated before it can be disposed of properly or discharged back to receiving water. Several factors must be considered when selecting an appropriate dewatering technology including physical characteristics of the sediment, selected dredging method, and the needed moisture content of the material to allow for the next re-handling, transport, or disposal steps in the process. Two main categories of dewatering that are regularly implemented include gravity dewatering and mechanical dewatering, as described below.

7.5.1.1 Gravity Dewatering

Gravity dewatering is facilitated through natural drainage of sediment porewater to reduce the dredged sediment water content. Gravity dewatering is usually applied to mechanical dredging process options because hydraulic dredging generates very large volumes of water that requires large areas. Gravity dewatering is facilitated through the use of temporary holding barges equipped with weirs or ballasts and filtration systems. Water generated during the dewatering is typically discharged to receiving waters at the construction location directly after settling and filtration. Normal passive dewatering typically requires little or no treatability testing, although characteristics of the sediment such as grain size, plasticity, settling characteristics, and contaminant content are typically considered to determine specific dewatering methods, to determine the size of the dewatering area, and to estimate the timeframe required for implementation. Recent dredging projects (EW T-18 Maintenance Dredging, and the LDW Slip 4 and T-117 Early Action Areas [EAAs]) indicate that project-specific water quality criteria can be met using gravity dewatering through filter media. In addition, project experience and analysis has shown that the contribution of suspended sediments to the water column from dewatering operations are generally less than the contribution from dredging operations. However, additional treatment of dewatering effluent may be considered during remedial design.

Gravity dewatering is generally effective and capable of handling variable process flow rates. Gravity dewatering is fairly simple, but this method can require significant amounts of barge capacity (depending on the volume of material processed and the settling characteristics of the sediment) and time for significant water content reduction.

On-shore gravity dewatering is not anticipated for the EW due to space limitation. Hydraulically dredged sediment dewatering with geotextile tubes[86] has been implemented at several sites to reduce space requirements, but typically still requires significant upland area

[86] A geotextile tube is a fabric enclosure that can be used to contain hydraulic dredge slurry and facilitate dewatering. The fabric is typically a woven geotextile that is selected so that the filtering characteristics of the textile allow discharge of relatively non-turbid effluent from the tube during dewatering. Containment by the tube imposes lateral stress on the dredge slurry, which facilitates more rapid dewatering of the dredge solids than would otherwise occur under passive (gravity) settling conditions.

and project-specific bench-scale evaluations during remedial design to confirm its compatibility with site sediments and to properly select and size the geotextile tubes.

Depending on the desired moisture content of the sediment, the subsequent processing or handling steps, the volume of material to be dewatered, available space, and the ability to effectively manage the dewatering effluent, passive dewatering can be a highly implementable dewatering technology option. Gravity barge dewatering was retained as a representative passive dewatering process option for inclusion in the development of alternatives, primarily because available disposal options can handle wet sediments (see Section 7.3). Other gravity dewatering options should be considered during remedial design.

7.5.1.2 Mechanical Dewatering

Mechanical dewatering involves the use of equipment such as centrifuges, hydrocyclones, belt presses, or plate-and-frame filter presses to separate coarse materials, or squeeze, press, or otherwise draw out water from sediment pore spaces. Mechanical dewatering is typically used in combination with hydraulic dredging to reduce the water content of the dredge slurry prior to beneficial reuse (e.g., sands retained from particle separation methods), ex situ treatment (e.g., thermal), or disposal of the dewatered sediment. A mechanical dewatering treatment train usually includes treating the dewatering effluent prior to discharge.

The mechanical dewatering treatment train typically includes screening to remove materials such as debris, rocks, and coarse gravel. If appropriate, polymers may be added for thickening prior to dewatering. These steps result in a dewatered cake that achieves project-specific volume and weight reduction goals of the dredged sediment. The mechanical dewatering process can be scaled to handle large volumes of sediment, but requires operator attention, consistent flow rates, and consistent sediment feed quality.

Mechanical dewatering is generally an effective technology for both hydraulic and mechanical dredging and has been implemented for a range of sediment types and sediment end uses (e.g., beneficial reuse and upland disposal). It is generally used where achieving moisture content reduction over shorter timeframes is needed. When identified as being needed, mechanical dewatering is evaluated in bench-scale tests during remedial design to develop the specific process design, select equipment, and to select polymer additives if appropriate. Mechanical dewatering costs are included for use with hydraulic dredging technologies; however, additional mechanical dewatering technologies may be considered during remedial design if a need is demonstrated.

7.5.2 Water Treatment

Water treatment refers to a system of tanks, filters, and other equipment used to process water generated during dewatering or transloading activities. Water treatment can be used in concert with either gravity dewatering or mechanical dewatering processes described above. Water treatment systems can be barge-mounted or constructed upland.

The FS assumes water treatment would be required at a transloading facility to manage water generated from dewatering of sediments. Discharge of treated water would likely be directly to the EW or other waterbody. Water treatment technologies in the uplands (e.g., for treatment of stormwater or industrial wastewater) are standard, myriad, and ubiquitous in their application to a wide variety of site-specific conditions. Treatment trains using conventional equipment are capable of treating water generated during sediment remediation projects to levels consistent with ARARs.

Discharge to the King County Metro sewer system could also be considered where the discharge meets flow (i.e., capacity) and chemical parameter limits. This approach would be an off-site disposal action, likely requiring pre-treatment to achieve discharge criteria and comply with all permit requirements (e.g., daily discharge volume), so as not to contribute to an overflow event (e.g., holding tanks for monitored flow).

Water treatment of dredged sediment barge water is assumed to be necessary for diver-assisted hydraulic dredging activities due to the large percentage of water generated compared to dredged sediment. For mechanical dredging, the FS assumes that additional water treatment beyond gravity dewatering (settling and filtration) will not be necessary to meet water quality standards in the construction area.

7.5.3 Best Management Practices

As previously described, short-term water quality impacts and residuals generation can be associated with contaminated sediment removal construction activities. These construction impacts can be mitigated to some degree using operational and barrier control BMPs. This subsection provides a summary review of a wide array of water quality and dredge residual BMPs and discusses the screening of these removal process options for this FS. Additional information regarding effectiveness, implementability, and costs of standard and specialized BMPs employed on environmental dredging projects is provided in Appendix B, Part 5. Standard BMPs are those specified in typical environmental dredging projects, used during dredging, transport, and offloading. The FS cost estimate for dredging assumes that standard BMPs would be employed. Specialized BMPs are sometimes specified during remedial design or triggered during implementation. Specialized BMPs may reduce suspended sediments, but typically reduce production rates, increase costs, and increase design and construction complexity. The FS cost and production rate estimate for dredging assumes that specialized BMPs would not be employed. Post-dredging residuals management contingency actions (RMC, re-dredging) are sometimes considered dredging BMPs, but are discussed in Section 7.2.6.5 and Appendix B, Part 5.

7.5.3.1 Standard BMPs

Operational controls impose limitations on the operation of the equipment being used for removal activities. Dredging BMPs are currently known and established, but may evolve until actual construction. For mechanical dredging, operational control BMPs that reduce re-suspension and loss of contaminated sediments may include the following:

- **Select appropriate dredge equipment:**
  - Conduct intertidal sediment and shoreline bank soil excavation “in the dry” to the degree reasonably possible using land-based equipment.
  - Include an option for an environmental or sealed bucket, where practicable (proper sediment conditions exist).
  - Properly select the dredge bucket for site conditions (i.e., soft sediment versus debris and/or hard digging) to maximize sediment capture and optimize fill efficiency. Adjust methods in changing site conditions.

- **Select dredge methods to increase accuracy and minimize releases:**
  - Perform dredging to the design dredge elevation in a single dredge event, as verified by periodic bathymetric surveys. Using sub-foot accuracy GPS for accurate bucket positioning.
  - Require a debris sweep prior to dredging in known debris areas (debris caught in dredging equipment can cause additional re-suspension and release of contaminated sediments).
  - Minimize the potential for slope failures by maintaining stable side slopes during dredging (e.g., shallow top-to-bottom cuts), including limiting the cut thickness of initial cut depths to avoid sloughing of the cut bank.
  - Start dredging in upslope areas and moving downslope to minimize sloughing.
  - Slow the rate of dredge bucket descent and retrieval (increasing dredge cycle time).
  - Limit operations during relatively high water velocity conditions (turbulence in the vicinity of the dredge bucket during high flow conditions can cause additional re-suspension and release of contaminated sediments).
  - Prevent "sweeping" or leveling by pushing bottom sediments around with dredge equipment to achieve required elevations.
  - Prevent interim stockpiling of dredge material under water.
  - Prevent the overfilling of conventional clamshell (i.e., "open") buckets.
  - Require the slow release of excess bucket water at the water surface.
  - Contain drippage during the overwater swing of a filled bucket (e.g., by placing an empty barge or apron under the swing path during offloading or loading containers directly on barges).
  - Use floating and/or absorbent booms to capture floating debris or oil sheens.
- **Water quality monitoring:**
  - Perform water quality monitoring during dredging to adaptively manage dredging operations and to comply with water quality requirements.
  - Adjust dredging methods (e.g., cycle times) as necessary based on water quality measurements.

- **Control dewatering operations:**
  - Control and reduce the silt burden in runoff from barges using weirs, filtration, and settling.
  - Time water discharges to maximize settlement and filtration efficiency.
  - Prevent overfilling of barges to minimize spillage from barges.
- **Control transload operations:**
  - Use barges that can be made watertight during transit and transloading to allow collection and treatment of generated water.
  - Control and reduce the silt burden in runoff from rehandling areas, using filtration.
  - Use spill plates and spill prevention measures.

Possible additional hydraulic dredging BMPs include the following:

- Changing the method of operating the dredge based on changing site conditions such as tides, waves, currents, and wind.
- Find an optimal rate and method of operation for a given set of conditions. Sediment resuspension is generally minimized at the same point that production is optimized.

7.5.3.2 Specialized BMPs

Engineered barrier controls at environmental dredging and capping sites typically include two different technologies (USACE 2008a):

- Silt curtains and silt screens
- Rigid containment (e.g., sheetpiles or cofferdams)

Each of these engineered barrier controls are discussed below.

Silt Curtains and Screens

Silt curtains and screens are specialized BMPs that have proven effective in reducing surface water turbidity in relatively quiescent environments and are a common BMP used to retain suspended sediment plumes at environmental dredging sites located in low-energy environments without deep water (Francingues and Palermo 2005). Water passes below or around fabric curtains because they are not typically sealed with the bottom. Water also discharges around the curtains when they are opened to allow the necessary passage of work equipment. As discussed in Bridges et al. (2010), based on a review of the available data, there is uncertainty as to whether silt curtains are effective in retaining contaminants within the curtain footprint, and there are also concerns that contaminants can migrate below the bottom of the curtain while the curtain is in place or upon curtain removal.

An evaluation of the effectiveness of silt curtains for environmental dredging was recently performed by Alcoa (under EPA oversight) within a relatively low-energy environment of the Lower Grasse River (Connolly et al. 2007). Water quality monitoring performed both inside and outside of the silt curtains revealed that the curtains had little effect in controlling downstream dredging-related releases of dissolved PCB concentrations, which made up roughly 69% to 89% of the total PCBs. Silt curtains achieved localized reductions in TSS concentrations, but did not appear to be necessary to achieve TSS-based water quality criteria (Alcoa 2006). Moreover, concentrated flow conditions beneath the silt curtains resulted in localized scour and re-suspension, which periodically increased downstream contaminant transport. These conditions limit the ability of the curtain to effectively contain dredging-related contaminant releases to the work area (EPA 2005).

Implementability concerns have also been documented on several projects, including the Lower Grasse River (Connolly et al. 2007), the San Jacinto River (Anchor QEA 2011), and other environmental dredging projects that deployed silt curtains (EPA 2005). For example, short-term pressure waves and flow increases in the Lower Grasse River routinely damaged the silt curtains. These issues are exacerbated in deeper water, which requires a deeper curtain that can act as a bigger "sail" and can also be difficult to effectively anchor. The displaced curtains can also become a hazard to navigation and/or block access to the work area, and the curtains often need to be frequently repositioned or re-anchored. Generally, the use of silt curtains and screens have significantly reduced overall dredge production rates (e.g., see Connolly et al. [2007]), and typically lead to significantly extended schedules to complete remediation, consequently increasing the impact from the dredging operation. For these reasons, and because the deep water depths in the EW would preclude the use of full curtains, silt curtains are not retained as a BMP.

Rigid Containment

As discussed in Bridges et al. (2010), rigid containment barriers (e.g., sheetpiles or cofferdams) are occasionally used to contain re-suspension during environmental dredging operations, particularly in high-energy environments, although with different technological limitations. The EW is not a high-energy environment and has technical limitations related to the implementation of a standard sheetpile wall as rigid containment. The maximum practical depth of water for sheetpiles in the EW is approximately 35 to 40 feet. Beyond that depth, the sheets cannot be embedded sufficiently to resist the lateral forces imposed by the water pressure. In areas deeper than 35 to 40 feet, a cellular cofferdam would need to be constructed for rigid containment. Cellular cofferdams have considerable implementability issues including the time required for construction and the hazard to navigation they would create once in place. Because of the construction duration, it is not practical to construct and remove a cellular cofferdam structure to accommodate seasonal work windows.

While several case studies have demonstrated reductions of dredging-related releases outside of the sheetpile-enclosed area (relative to releases that would have occurred without containment), release of contaminants beyond the barrier still occurs, as in practice it has not been possible to place a watertight barrier. For example, during the Hudson River Phase 1 environmental dredging project, roughly 1% of the mass of PCBs dredged within sheetpile enclosure areas was released through the barrier, largely due to leakage through ports at the interlocks (Anchor QEA and Arcadis 2010).

Removal of rigid barriers can also have unintended and undesirable consequences. Adhered sediment can be re-suspended into the water column during pile pulling, resulting in re-suspension of deeply buried contaminants. Recontamination of adjacent sediment cap areas occurred during removal of a wall at Colman Dock in Seattle, due to mobilization and release of deeply buried PAHs in the area (Ecology 1995). Furthermore, suspended- or dissolved-phase contaminants may still be present in the water column at the time that the sheetpile are removed, resulting in release of contamination. Another limitation to rigid containment is the reduction in waterway width during placement, thereby reducing the cross section area for flow and increasing flow velocities and scour potential.

The use of rigid containment is not expected in the EW, and not retained for the remedial alternatives.

7.6 General Site Conditions Affecting Remedial Technology Selection

The preceding sections described the site-wide screening and application of remedial technologies. Table 7-2 provides a summary of considerations for applying remedial technologies within the EW OU. The purpose of the table is to provide a single summary of the framework used for the CMA-specific evaluation of remedial technologies in subsequent sections. Additional information on specific constraints associated with each CMA is provided in Section 7.7. Section 7.8 describes the applicability of individual technologies within each CMA.

7.7 Construction Management Areas

The EW OU is an industrial waterway with structures (e.g., pile-supported piers, bridges, and riprap slopes) located in nearly all shoreline areas. Sediments with COCs above RALs are located under and adjacent to these structures in many areas of the EW OU, which restricts the technical and economic feasibility of implementing specific technologies and process options. Specific factors that may restrict the implementability include site access (e.g., feasibility of staging from upland facilities, homeland security issues within Pier 36); physical obstructions and structural conditions such as piers, bridge structures, or partially demolished aquatic structures; water depths (i.e., site bathymetric conditions); and navigation and other site use considerations. Based on these factors, the EW has been divided into specific CMAs that represent areas with similar structural conditions, or similar aquatic use, habitat, or water depth conditions.[87] These CMAs are shown on Figure 7-1 and defined in Table 7-3.

Structural restrictions and use, habitat, and water depth considerations associated with various areas of the EW are described in Sections 7.7.1 and 7.7.2, respectively, and shown on Figure 7-1. Figures 2-9 and 2-10 show typical underpier cross sections for T-18 and T-25/ T-30, respectively, which identify key structural elements described in Section 7.7.1.

[87] The CMAs were slightly modified since the Screening Memo (Anchor QEA 2012) by further subdividing CMAs into smaller areas for the purpose of evaluating applicable remedial technologies.

Table 7-2
Summary of General Site Conditions Affecting Remedial Technology Selection

Technology	Elevation Requirements and Restrictions[a]	Sediment Stability	Implementability
Removal	**Navigation channel and berthing areas:** No restrictions on vertical extent of removal, except as limited by practicability (e.g., adjacent structures). **Habitat areas (depths shallower than -10 feet mean lower low water):** Assume backfill to existing grade following removal to maintain habitat. Surficial material will consist of suitable habitat substrate.	Slope transitions will be designed with appropriate side-slopes (e.g., 3 horizontal to 1 vertical [3H:1V] or shallower).	Full removal is defined as removal to the extent practicable in all areas. The FS assumes that no structures will be removed, which is not practicable in all locations. In underpier areas, under bridges, near engineered shorelines (e.g., piers, riprap, bulkheads, and slopes), and near utilities, removal will be limited by structural considerations and offsets will be considered adjacent to structures.
Partial Dredging and Capping	**Navigation channel and berthing areas:** Partial dredging is assumed to be completed so that the top of the cap has an appropriate clearance below the authorized navigation depth in the navigation channel to account for overdredge and the vertical accuracy of dredging equipment. Figure 7-2 displays the current authorized dredge depths by area. **Habitat areas:** Partially dredge to the thickness of the cap, and cap to grade. Finish with habitat-suitable substrate.	Capping is engineered with appropriate stone size for scour mitigation; cap thickness considering contaminant transport, scour, and consolidation; and slopes for geotechnical stability. For the FS, a cap thickness of 5 feet is assumed, with slope transitions typically designed at 3H:1V or shallower, and the potential need to design and construct steeper slopes in limited locations due to site restrictions. The toe of slopes for areas adjacent to the navigation channel are assumed to have appropriate horizontal and vertical clearance to account for future maintenance dredging activities.	Partial dredging is limited by structural considerations, as described for removal above. Capping is limited by structural considerations, such as the impact of material on piles and settling of underlying sediment.
Enhanced Natural Recovery (ENR)	**Navigation and berthing areas:** Partial dredging is assumed to be completed in areas shallower than the authorized (channel) and maintained (berth areas) navigation depth so that the top of the ENR has an appropriate clearance below the authorized navigation channel depth to account for overdredge and the vertical accuracy of dredging equipment. **Habitat areas:** ENR is not restricted based on habitat.	ENR is generally applicable in locations with limited scour potential; however, mixing is an aspect of ENR. The grain size or thickness of ENR material can be adjusted to improve the stability characteristics of the ENR layer.	ENR is applicable in some areas with access limitations (i.e., under the low bridge areas) because other remedial technologies are not constructible. ENR is not applicable to some underpier areas (T-18, T-25, Slip 27, T-30, and T-46) due to instability on steep slopes.
In situ Treatment	**Navigation and berthing areas:** In situ treatment is not assigned in navigation or berthing areas because other implementable and effective technologies are available in these locations. **Habitat area:** In situ treatment is not restricted based on habitat.	The in situ treatment layer is expected to mix with underlying sediment. The grain size of in situ material could be adjusted to improve the stability characteristics of the in situ treatment layer.	In situ treatment is anticipated to be applicable in areas with practicability concerns (i.e., underpier areas), due to the particle sizes, and minimal thickness of material being placed. In situ treatment is more constructable than capping or ENR in underpier areas.
Monitored Natural Recovery (MNR)	No elevation requirements or restrictions.	MNR is generally applicable in locations with higher sedimentation rates and less scour. MNR effectiveness may be improved when combined with remediation of adjacent areas (e.g., underpier areas adjacent to removal with residuals management cover areas).	MNR is suitable for difficult-to-access areas because of the inability to meet remedial action objectives with other remedial technologies, particularly when combined with remediation of adjacent areas.
Institutional Controls	Will be applied to all areas of the East Waterway Operable Unit.	Not affected by stability.	Can be implemented at the site, although has effectiveness concerns.

Note:
a. As discussed in Section 2.9.2, USACE completed a draft Seattle Harbor Navigation Improvement Project Feasibility Report and Environmental Assessment in August 2016, which includes alternatives for deepening and widening the federal navigation channel. Because the implementation of the navigation improvement project is uncertain, the assumptions for remedial technologies (e.g., post-capping elevation requirements) are based on current conditions and uses. However, all EW remedial technologies are also compatible with the future implementation of the potential navigation improvement project, and the navigation improvement would not reduce the environmental protectiveness of the remedy in the EW.

FS – Feasibility Study   T – terminal   USACE – U.S. Army Corp of Engineers

Table 7-3
Construction Management Areas in the East Waterway

Construction Management Area	Description	Structural Restrictions	Use, Habitat, and Water Depth Considerations
Junction Reach	Located south of the Spokane Street corridor and north of the junction with the LDW. Both west and east sides of the EW in this area contain riprap slopes, with floats for small vessels along the west side of the waterway.	Piles and small vessel floats are present in the waterway, but present minimal structural restrictions in this area. It is assumed that dredging adjacent to the piles should be minimized, and dredging at the base of slopes should consider overall slope stability. Existing riprap slopes may limit the ability to conduct remediation immediately adjacent to the riprap slopes without slope improvements.	A shallow bench along the eastern shoreline at T-104 was constructed of fine-grained substrate and provides valuable shallow water habitat for juvenile migratory fish, and intertidal areas provide clam habitat. Small draft recreational and commercial boats move in and out of the Harbor Island Marina (T-102) from the LDW. Tribal netfishing may occur within this area.
Sill Reach	Located under the bridges in the Spokane Street corridor. Four bridge structures pass through this area, including the Spokane Street Bridge and Service Road Bridge between T-102 and T-104, West Seattle Bridge, and BNSF Railway (Railroad Bridge). Elevations in this area range from -4 to -11 feet MLLW.	The West Seattle bridge columns located in the water on each side of the EW are supported by a pile-supported footing or pile cap (approximately 26 feet by 32 feet each) with top of footing at approximately -7 feet MLLW. There are similar-sized pile caps for columns upland on each side of EW. Additional areas adjacent to these columns may have seen some soil improvements that provide additional structural stability to the column and should be considered if significant soil were to be removed. The existing bridge structures limit access for equipment and may restrict removal and/or containment remedial actions underneath the bridges, or immediately adjacent to the bridge structures. The bridge structures are considered critical infrastructure to transportation needs.	Clam habitat is present in intertidal areas. Habitat restoration is proposed for the west side of the EW under the West Seattle Bridge, which would provide off-channel mudflat and marsh habitat, along with riparian vegetation. The project would also involve removal of debris and creosote structures from the shoreline areas. The restoration is subject to Natural Resource Damage Trustee approval, EPA coordination, and obtaining permitting from federal, state, and City agencies. No timeline is established for construction.
Shallow Main Body – South	Located north of the Sill Reach before the EW widens to its full 750 feet width. This area is used to moor tugs and barges along the western side, where a concrete bulkhead is present. There is also a wooden wharf pile-supported structure in-line and to the south of the concrete bulkhead. Details on the date and type of original construction of these structures are unknown. This CMA is within the portion of the federal navigation channel authorized to -34 feet MLLW.	Design and construction details of the concrete bulkhead and timber wharf structure on the west side of the EW are unknown. The condition of the concrete structure is relatively poor, however, based on visual observation. Dredging adjacent to the bulkhead may cause structural impacts.	Numerous barges and tugboats are moored along the west side of the CMA. This CMA also contains a mound of rock placed in the southeast portion of this area specifically for habitat restoration purposes. The mound provides shallow water habitat just north of the Spokane Street pedestrian bridge. Tribal netfishing occurs within this area. Shoreline slope stabilization has recently been proposed along the northwest corner of this CMA (independent of CERCLA).
Former Pier 24 Piling Field	A timber bulkhead and timber piles are present along the southern shoreline of Pier 24. The top of the existing bulkhead is lower than high tides. Removal is planned for these piles, a small pier, and in-water debris, which occupy approximately 2.1 acres of aquatic and shoreline area for fish and wildlife habitat improvements. No timetable for this work is currently established based on the need to coordinate with CERCLA actions. This work may be completed in conjunction with the CERCLA action or may be conducted for habitat restoration purposes ahead of the CERCLA action.	Removal or cutting of piles would be required prior to implementation of remedial alternatives in this area. Structural condition of the existing bulkhead wall is severely deteriorated. As such, removal of the piles and/or any dredging in this area will require strengthening of this wall or removal of the wall plus associated upland grading to contour in-water and upland slope to final desired grades.	This area is potentially slated for Port habitat restoration.
Shallow Main Body – North	Located north of where the EW widens to its full 750 feet and south of the navigation area maintained at -51 feet MLLW. This area extends approximately from Station 4950 to Station 6200 and is included in the portion of the federal navigation channel authorized to -34 feet MLLW.	No structural restrictions.	The water depths in this area reach a maximum depth of -45 feet MLLW (except for the berthing area at T-25, which was designed for -50 feet MLLW). Some limited vessel navigation occurs in this area, including container ships to T-25 at high tide. Tribal netfishing occurs within this area.

Table 7-3
Construction Management Areas in the East Waterway

Construction Management Area	Description	Structural Restrictions	Use, Habitat, and Water Depth Considerations
Underpier Areas	Underpier areas apply to T-18, T-25, Slip 27, T-30, Pier 36/37, and T-46 and extend from approximately 125 feet shoreward of the Pier Head Line.	Due to very limited access to underpier areas, only from the water, it is considered extremely difficult to remove sediments from the underpier slopes. Specialized dredging equipment may be capable of removing some of the underpier sediment, but not 100% of sediment. Any underpier removal work would likely need to be conducted using diver assisted methods, and the risks for injury and death during construction will need to be weighed against long-term risk of leaving contaminated sediment in underpier areas. Capping or placement of certain ENR materials within the underpier areas may be infeasible due to equipment access and placement issues. Also, the underpier slopes are typically too steep to place a stable cap over them, and a potential drawdown effect on piling from placing material on the slopes may cause structural damage.	Underpier areas provide habitat for rockfish and epibenthic food for salmon. However, in situ treatment in underpier areas is not restricted based on habitat.
Berth Areas (T-18, T-25, T-30)	Berth areas extend along T-18, T-25, and T-30 and are approximately 150 feet wide. Berth areas at T-18 and T-25 extend from the pier head line into the federal navigation channel.	Berth areas within the EW are actively used by a variety of vessels, the largest of which are container ships. Required berthing elevations typically match the federal navigation channel's authorized elevation of -51 feet MLLW. Removal in front of these terminals may need to limit dredging depths and may include setback areas from the structures to avoid adversely impacting the existing pile-supported wharves. At T-18, a sheetpile wall was installed to provide slope stability to allow dredging along the toe of slope between approximate Stations 4950 and 1900 (terminating at Communication Cable Crossing at bent 213). The capacity of the existing sheetpile wall limits any significant additional material removal at the toe of slope; the sheetpile was designed for a dredge elevation of -51 feet MLLW. The keyways at the base of riprap slopes at T-25 and T-30 are at approximately -50 feet MLLW. For T-18 south of Station 4950, no sheetpile wall exists; T-25 has not had any significant structural berth deepening performed since initial construction in the 1970s. As such, it is unlikely that the structure can accommodate dredging below the initial design dredge elevation. Recent improvements at T-30 (accomplished by the Port in 2007) were completed to allow for dredging in the berth area to -50 feet MLLW.	Along T-18, berthing area elevations are -51 feet MLLW from Station 0 to 4950. Berth 6 (south of Station 4950) depths at T-18 are approximately -35 to -40 feet MLLW. Along T-25, berthing area elevations are -50 feet MLLW. Along T-30, berthing area elevations are -50 feet MLLW. Tribal netfishing occurs within these areas.
Slip 27 Channel/ Pier 28	Slip 27 is located on the east side of the EW, between T-25 and T-30. It is 850 feet long and 240 feet wide. Pier 28 is the concrete structure located on the north side of Slip 27.	A 34-foot-wide truck bridge is present in the eastern portion of Slip 27 connecting T-25 and T-30. This bridge is located to the west of a structural bulkhead wall. The wall and bridge will likely limit the maximum depth of dredging in this area. Pier 28 is a concrete deck and concrete pile structure that is considered at or near the end of its useful life. Structural observations of this facility in 2001 indicate that the pier is deteriorated.	Miscellaneous vessels berth in Slip 27. Pier 28, at the northern portion of the slip, is currently used to berth various vessels and barges. The Slip 27 and Pier 28 areas provide shallow water habitat for juvenile migratory fish, and intertidal areas provide clam habitat. Tribal netfishing occurs within this area.
Slip 36/ T-46 Offshore	Slip 36 is located on the east side of the EW, between Pier 36 and Pier 37. It is approximately 1,200 feet long and 300 feet wide.	Recent construction work on Pier 36 and within Slip 36 included dredging the berth areas to -40 feet MLLW. Further sediment removal may be limited without structural impacts. Recent dredge work at Terminal 46 determined that a non-structural maintenance dredge was possible to allow a berth depth of -51 feet MLLW. Further deepening of the berth area along the west face of the Pier 46 apron would likely require associated structural improvements.	USCG vessels frequent Slip 36, which serves Pier 36 (south) and Pier 37 (north). The western half was dredged to -40 feet MLLW in 2005. USCG berths numerous vessels in Slip 36, and has homeland security access restrictions.

Table 7-3
Construction Management Areas in the East Waterway

Construction Management Area	Description	Structural Restrictions	Use, Habitat, and Water Depth Considerations
Mound Area/ Slip 27 Shoreline	This area is located on the east side of the EW just south of the mouth of Slip 27 and along the southern and eastern shoreline of Slip 27. It is open slope, typically with a riprap face.	Possible that structural walls could be necessary to accomplish significant removal of material along this slope without impacting the slope and/or yard area above.	The upland areas along the southern part of Slip 27 have been replanted as part of habitat restoration. The restoration extends from the top of bank (18.5 feet MLLW) down to 12 feet MLLW. The shallow water and intertidal areas also provide habitat for clams and juvenile salmon. Tribal netfishing occurs within this area.
T-25 Nearshore	This area is located on the east side of the EW, between the T-25 Pier and the Mound Area. It is open slope, typically with a riprap face.	Possible that structural walls could be necessary to accomplish significant removal of material along this slope without impacting the slope and/or yard area above.	The shallow water and intertidal areas also provide habitat for clams and juvenile salmon. Tribal netfishing occurs within this area.
T-30/Coast Guard Nearshore	This area is located on the east side of the EW, between Slip 27 and Slip 36.	This area includes several deteriorated structures including remnant piers and both sheetpile and rock bulkhead walls. The specific structural condition of all structures is unknown but appears to be severely deteriorated, suggesting that additional dredging and slope modifications would be problematic without associated structural improvements. This FS assumes that the derelict structures may be removed to facilitate remediation as needed.	Jack Perry Park is a 1.1-acre park located north of T-30 and south of the USCG facility. It provides 120 feet of intertidal area and shoreline access for public recreational activities. Smaller vessels, such as tugboats, barges, and Tribal fishing vessels navigate in this nearshore area. Future development along the shoreline of T-30 is possible, which could result in water depth requirements of -50 feet MLLW (the same as the current T-30 berth area water depth requirements). Shoreline areas provide shallow water habitat for juvenile migratory fish, and intertidal areas provide clam habitat. Tribal netfishing occurs within this area.
Communication Cable Crossing	A communications cable crosses the EW between T-18 and the northern portion of T-30 (Figure 7-1). This cable was originally buried between -61 and -66 feet MLLW in 1972 in an armored trench. The location shown on Figure 7-1 changed following repair due to a vessel anchor incident at T-18. During the T-18 North Apron Upgrade in 2006, the existing crossing at the T-18 face of bullrail was located between bents 213 and 214 (Station 1850). On the T-30 side, the approximate crossing location is indicated by a visible marker on the shore (Station 1550).	For the purposes of this FS, it is assumed that the depth of sediment removal may be limited in this area by the presence of the cable crossing.	Water depths in the footprint of the cable crossing range from -53 feet MLLW to -59 feet MLLW in the federal channel and berth areas. Vessel use is similar to the navigation channel, T-18, and T-30. Tribal netfishing occurs within this area.
Deep Main Body – North	The Deep Main Body – North is 450 feet wide and extends from Station 0 to between Stations 2970 and 3590, depending on location (boundary varies from east to west as shown on Figure 7-2). The channel is authorized to -51 feet MLLW, and maintained to -51 feet MLLW.	No structural restrictions.	The authorized channel elevation of -51 feet MLLW is required to support movement of large container ships throughout the EW. Most vessel traffic consists of shipping companies moving container ships and assorted tugboats into and out of the EW. Each container ship requires at least one tugboat to maneuver the ship during docking and undocking. Container ships call at T-18, T-25, and T-30. Other vessels, such as tugboats, barges, and USCG vessels, regularly use the navigation channel. Also note the Communication Cable Crossing described earlier in this table. Tribal netfishing occurs within this area.

Table 7-3

Construction Management Areas in the East Waterway

Construction Management Area	Description	Structural Restrictions	Use, Habitat, and Water Depth Considerations
Deep Main Body – South	The Deep Main Body – South is 450 feet wide and extends from Station 4950 to between Stations 2970 and 3590, depending on location (boundary varies from east to west as shown on Figure 7-2). It is within the federal navigation channel and is authorized to -34 feet MLLW but is maintained to -51 feet MLLW.	No structural restrictions.	Maintenance of this portion of the authorized channel to -51 feet MLLW is required to support movement of large container vessels into berthing areas at T-18 and T-25. Most vessel traffic consists of shipping companies moving container ships and assorted tugboats into and out of the EW. Each container ship requires at least one tugboat to maneuver the ship during docking and undocking. Container ships call at T-18 and T-25. Other vessels, such as tugboats, barges, and USCG vessels, regularly use this area. Tribal netfishing occurs within this area.

Notes:

BNSF – BNSF Railway
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
CMA – Construction Management Area
ENR – enhanced natural recovery
EPA – U.S. Environmental Protection Agency
EW – East Waterway
FS – Feasibility Study
LDW – Lower Duwamish Waterway
MLLW – mean lower low water
Port – Port of Seattle
USCG – U.S. Coast Guard
T – Terminal

7.7.1 Structural Restrictions

A number of structural restrictions present in the EW may preclude the use of specific remedial technologies due to limited site access or potential for adverse impacts to structural or slope stability. The proximity to these structures may limit the ability to implement certain remedial technologies or process options. Detailed information on adjacent facilities and infrastructure is found in the EISR (Anchor and Windward 2008a). A summary of these structural restrictions and the assumptions developed in the absence of detailed structural information are provided in Table 7-3. Figures 2-9 and 2-10 show detailed structural information that is available for T-18, T-25, and T-30.

7.7.2 Use, Habitat, and Water Depth Considerations

Use, habitat, and water depth considerations in the EW could potentially limit the range of remedial technologies that could be considered for specific CMAs. The navigation channel and berthing areas have minimum water depths required for vessel operations. Navigation for container ships and other smaller vessels is a current and anticipated future use of the EW navigation channel and adjacent berths. Therefore, maintenance dredging depth requirements must be considered for remediation. In addition, as described in Section 2.9.2, USACE completed a draft SHNIP Feasibility Report and Environmental Assessment in August 2016, which includes alternatives for deepening and widening the federal navigation channel. Because the implementation of the navigation improvement project is uncertain, the assumptions for the EW FS alternatives are based on current conditions and uses but are compatible with the future implementation of the potential deepening of the navigation channel, and the navigation improvement would not reduce the environmental protectiveness of the remedy in the EW.

Intertidal and nearshore habitats may be home to diverse communities of fish, birds, and invertebrate species. Therefore, areas with depths shallower than -10 feet MLLW will be managed in ways that approximately restore pre-construction elevations. These considerations are detailed in Table 7-3 and shown on Figure 7-1.

7.8 Summary of Representative Process Options for the Feasibility Study

A summary of the screening of remedial and disposal technologies for the EW OU is provided in Table 7-4. This table combines the information in the preceding sections to provide a CMA-specific screening of remedial technologies. For the purpose of assigning remedial technologies, the CMAs are grouped into eight areas based on similarity of physical features and potential remedial actions. The following sections discuss the eight groups of CMAs and the applicable remedial technologies retained or eliminated for each. This screening was based on the Screening Memo (Anchor QEA 2012a); however, modifications were made based on further analysis of the site. Some technologies were eliminated based on additional considerations, resulting in fewer remedial technologies retained for individual CMAs in the FS than in the Screening Memo. As discussed previously in this section and in the Screening Memo, the applicability of the remedial technologies could be revisited during remedial design, as conditions dictate.

7.8.1 Deep Main Body and Berth Areas

The Deep Main Body and Berth Areas include eight CMAs:

1. Deep Main Body – North
2. Deep Main Body – South
3. T-18 Berth Area
4. T-30 Berth Area
5. T-25 Berth Area
6. Slip 27 Channel
7. Slip 36 Channel
8. T-46 Offshore

These CMAs are characterized by elevation constraints from maintenance dredging and potential for vessel propwash scour from maneuvering vessels. Maintenance dredging elevations range from -51 to -35 feet MLLW.[88] Removal, capping (with partial dredging), and ENR (with partial dredging) were retained for these areas; MNR and in situ treatment were eliminated.

[88] As discussed in Section 2.9.2, the maintenance dredging elevations could be modified in the future if the SHNIP is funded and implemented. Retained technologies are compatible with potential EW navigation channel deepening.

Table 7-4
Applicability of Retained Remedial Technologies to East Waterway Construction Management Areas[a]

Construction Management Areas (CMAs)	No Action	Natural Recovery		In situ Treatment	In situ Containment	Removal
		Monitored Natural Recovery (MNR)	Enhanced Natural Recovery (ENR)	Amendments	Capping or Partial Dredging and Capping	Dredging or Dry Excavation
Deep Main Body, Shallow Main Body, and Berth Areas – Deep Main Body, Deep Draft Berth Areas (T-18, T-30, T-25), Slip 27 Channel, and Slip 36/T-46 Offshore	**Retained**	**Eliminated**	**Retained**	**Eliminated**	**Retained**[b]	**Retained**
Underpier Areas	**Retained**	**Retained**	**Retained** for Slip 36 underpier areas **Eliminated** for all other underpier areas (T-18, T-25, Slip 27, T-30, and T-46)[c]	**Retained**	**Retained** for Slip 36 underpier areas **Eliminated** for all other underpier areas (T-18, T-25, Slip 27, T-30, and T-46)[c]	**Retained**[d]
Shallow Main Body Reach	**Retained**	**Eliminated**	**Retained**[e]	**Eliminated**	**Retained**	**Retained**
Sill Reach – West Seattle Bridge and low bridges (Railroad Bridge and Spokane Street Bridge)	**Retained**	**Retained** for the low bridge areas (Railroad Bridge and Spokane Street Bridge) **Eliminated** for the West Seattle Bridge area	**Retained**	**Retained**[f]	**Eliminated**	**Retained** for the West Seattle Bridge area **Eliminated** for the low bridge areas (Railroad Bridge and Spokane Street Bridge)
Junction Reach	**Retained**	**Retained**[g]	**Retained**[g]	**Retained**[g]	**Retained**[g]	**Retained**
Former Pier 24 Piling Field	**Retained**	**Eliminated**	**Retained**[h]	**Eliminated**	**Retained**	**Retained**
Nearshore Areas (not used as Berths) – Mound Area/Slip 27 Shoreline, Coast Guard Nearshore, T-25 Nearshore, and T-30 Nearshore	**Retained**	**Eliminated**	**Eliminated**	**Eliminated**	**Retained** for Mound Area/Slip 27 Shoreline and Coast Guard Nearshore **Eliminated** for T-25 Nearshore and T-30 Nearshore	**Retained** for T-25 Nearshore and T-30 Nearshore **Eliminated** for Mound Area/Slip 27 Shoreline and Coast Guard Nearshore
Communication Cable Crossing	**Retained**	**Eliminated**	**Retained**	**Eliminated**	**Eliminated**	**Retained**

Notes:
a. The technology screening is only for FS purposes; all technologies may be considered during remedial design.
b. Although capping is retained for these CMAs, no alternative incorporates capping because the partial dredging depth needed to gain clearance for the cap is deeper than the contamination thickness in most locations. Therefore, most contamination would be removed by partial dredging, making capping unnecessary.
c. Slopes in T-18, T-25, Slip 27, T-30, and T-46 underpier areas are too steep for ENR or capping placement.
d. Diver-assisted hydraulic dredging was retained for underpier areas since removal using mechanical dredging equipment is not feasible in these areas.
e. Although partial removal and ENR was retained in the Shallow Main Body Reach, there is no alternative that incorporates this technology for this CMA because only small areas of the Shallow Main Body Reach were applicable for ENR-nav, and broader areas were applicable for partial removal and capping. Therefore, partial removal and capping was retained for the alternatives.
f. In situ treatment was retained in the Sill Reach; however, in situ treatment was not incorporated in the alternatives in the Sill Reach because other more common and effective remedial technologies are available. In particular, coarser-grained and more dense sand and gravel that would be specified for ENR are likely to be stable and effective in the location.
g. Although MNR, ENR, in situ treatment, and capping were retained for this in the Junction Reach, there are no alternatives that incorporate these technologies in this CMA because the alternatives that include remediation of the Junction Reach focus on removal.
h. Although ENR is retained for the Former Pier 24 Piling Field for consideration during design, ENR is not incorporated into the remedial alternatives for this CMA because of the only small areas were applicable for ENR-nav, and broader areas were applicable for partial removal and capping, therefore partial removal and capping was retained for the alternatives.
Institutional controls are part of all alternatives.
FS – Feasibility Study
T – terminal

Removal was retained for these CMAs for the reasons summarized in Section 7.2.6.6. As discussed in that section, shoreline structures such as piers will limit full removal in some locations. Shoreline structures are assumed to remain intact during remediation, and contamination left behind due to structural considerations will be addressed as part of residuals management following removal activities.

Capping was retained in conjunction with partial removal to gain clearance for future maintenance and navigation activities described in Section 7.2.5.3. Although partial removal and capping was retained in this screening, there is no alternative that incorporates this technology because the thickness of contamination is less than the required partial dredging depth in most locations. Therefore, most contamination would be removed by partial dredging, making capping unnecessary.

ENR was retained in conjunction with partial removal as necessary to gain clearance for maintenance and navigation activities (i.e., so the top of the placement layer is below the authorized or maintained navigation depth). ENR was incorporated into the remedial alternatives as ENR-nav, which would include additional measures to accelerate natural recovery and to mitigate the impact of vessel scour on surface sediment chemistry in the biologically active zone in areas that potentially have deep sediment mixing. For the FS, this is assumed to be a thicker layer of ENR with an average thickness of 18 inches (in order to achieve a minimum of 15 inches), which is roughly double the typical ENR application of 9 inches in other ENR areas). The thicker layer would mitigate the impact of scour by increasing the scour depth necessary to impact underlying sediment and increase the mass of clean sediment to mix with underlying sediment. In addition, this FS assumes that ENR-nav would only be employed in areas with relatively low sediment concentrations (e.g., between RALs and 2x RALs) to further reduce the impact of potential mixing of ENR-nav material with underlying sediment.

MNR was eliminated due to potential for resuspension of surface and subsurface contaminated sediment from erosive forces from propeller wash, and because future maintenance dredging could remove newly deposited sediment. In situ treatment was eliminated because other more common and effective remedial technologies are available. In particular, in situ treatment has not been used in areas with prop-scour forces similar to the

EW, and there are concerns that AC, which has a lower density than native sediments, may not be stable over the long term in areas where resuspension can occur.

7.8.2 Underpier Areas

The EW contains aprons, docks, and overwater structures (generalized here by the term piers) along the east and west shorelines. Piers over water represent approximately 14 acres of sediment of the EW OU. Piers present special challenges for addressing contaminated sediment residing underneath and adjacent to these structures. In general, the underpier areas are characterized by the following:

- Access limited by piers and piles
- Pile stability considerations and other structural considerations
- Steep slopes (stabilized with riprap, bulkhead, or sheetpile)
- Close proximity to SDs and CSOs
- Potentially high-energy environment due to maneuvering vessels

Only three technologies are considered suitable for meeting the technical challenges of remediating underpier areas: MNR, in situ treatment, and removal to the maximum extent practicable. ENR and capping are not included in the EW FS alternatives because of the small area where these technologies are applicable. However, ENR and capping may be considered during remedial design for underpier areas with slopes less than 1.75H:1V (e.g., Slip 36).

Although the underpier areas are a relatively high-energy environment, MNR was retained for underpier areas for several reasons. First, most other remediation technologies will be challenging to implement under piers; therefore, MNR is significantly more practicable than other forms of remediation. Second, underpier areas have high recovery potential following the remediation of adjacent open-water areas because of sediment exchange between these areas (the sediment exchange may also result in higher concentration sediments being deposited in open-water areas, as demonstrated by modeling results). Third, underpier areas have relatively small spatial extent and, therefore, are expected to contribute less to site-wide risks from bioaccumulative compounds, as shown in model predictions (e.g., see Appendix J sensitivity runs for Alternative 1A(12)).

In situ treatment was retained because it is anticipated to reduce bioavailability of contaminants with relatively small amounts of placed material. The thin layer of material is more likely to stay in place on steep slopes than a thicker ENR layer and has fewer constructability challenges than construction of a stable cap over a steep riprap slope. Potential methods for placing in situ treatment materials under the piers are discussed in Section 7.2.7.1.

Standard removal using mechanical dredging equipment is not feasible when working in underpier areas; therefore, diver-assisted hydraulic dredging was retained for underpier areas. Dredging in underpier areas has the most practicability and construction (i.e., diver) health and safety concerns compared to other remedial technologies. This FS assumes that a contractor would conduct diver-assisted hydraulic dredging by working around and underneath the existing pier structures to remove as much of the contaminated sediment as practicable above the slope riprap layer.

Because of technical challenges, complete removal of all contaminated sediment not being possible, diver health and safety concerns, and high cost of dredging the underpier areas, limited removal was retained to remove sediment with the highest concentration (e.g., hot spot areas). A dredging-specific action level was developed for FS costing purposes to address areas with the highest contaminant concentrations under the piers. For select alternatives, underpier sediment with concentrations above CSL for PCBs and mercury (65 mg/kg OC and 0.59 mg/kg dw, respectively) would be dredged. In situ treatment would be applied to the rest of areas with surface sediments exceeding RALs, as described above. These thresholds were developed based on the expectation that areas remaining above RALs but below these higher thresholds will be reduced to acceptable levels through in situ treatment.

In addition to limited removal in underpier areas, removal to the maximum extent practicable was also retained for select remedial alternatives to compare the costs and benefits of extensive hydraulic dredging under the piers.

Capping, partial dredging and capping, and ENR were not retained for some underpier areas (T-18, T-25, Slip 27, T-30, Pier 36/37, and T-46) due to the inability of placing and stabilizing a thick layer of material on steep slopes and around piles. These technologies may be considered during remedial design in less steep underpier areas (e.g., Slip 36), where they may be feasible.

7.8.3 Shallow Main Body Reach

At the southern extent of the federal navigation channel, the maintained navigation elevation changes from a maximum elevation of -51 feet MLLW to -34 feet MLLW. As shown in Figure 7-1, this area is split into the two Shallow Main Body Reach CMAs, the North, from Stations 4950 to 6200, and the South, from Stations 6200 to 6850. Although the authorized navigation elevation is -34 feet MLLW, the Shallow Main Body – North CMA has deeper water depths and some maintained berth areas (maximum elevation of -45 feet MLLW). The existing elevations in the Shallow Main Body – South CMA vary significantly (e.g., changes from an elevation of -40 feet MLLW at Station 6200 to -10 feet MLLW at Station 6850). Dredging, capping (with partial dredging), and ENR (with partial dredging) were retained for these areas; MNR and in situ treatment were eliminated.

Removal was retained for these CMAs for the reasons summarized in Section 7.2.6.6. As discussed in that section, shoreline structures such as piers will limit full removal in some locations. Shoreline structures are assumed to remain intact during remediation, and contamination left behind due to structural considerations will be addressed as part of residuals management following removal activities.

Capping was retained in conjunction with partial removal to gain appropriate clearance for future maintenance and navigation activities described in Section 7.2.5.3. For the Shallow Main Body Reach – North, the current site uses require that the elevation be maintained at approximately -40 feet MLLW, based on discussions with the Port's tenants. The maintenance depths based on reasonably anticipated future use will be revisited in remedial design. Based on the current bathymetry and maintenance depth assumptions, a cap could be placed over much of the CMA with limited partial dredging prior to cap placement. For the Shallow Main Body Reach – South, the area is not maintained at the authorized elevation of -34 feet MLLW. Based on current use (Olympic Tug and Barge is located on the west bank), this area could be reauthorized to a -30 feet MLLW navigation elevation, and a cap could be placed over most of the CMA with limited partial dredging prior to placement. Reauthorization to -30 feet

MLLW is assumed for partial dredging and capping in this FS, but actual depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process. In some deep locations, placement without partial dredging may be possible while still maintaining navigable water depths. For the FS, the technology assignment in the Shallow Main Body Reach CMA is referred to as partial dredging and capping; however, some areas may be capped without partial dredging if determined during remedial design.

ENR was retained in conjunction with partial removal to gain appropriate clearance for future maintenance and navigation activities described in Section 7.2.5.3. Although partial removal and ENR was retained in this screening, there is no alternative that incorporates this technology because there is sufficient clearance for partial removal and capping in the Shallow Main Body Reach.

MNR was eliminated due to potential for resuspension of surface and subsurface contaminated sediment from erosive forces from propwash and because future maintenance dredging could remove newly deposited sediment and placed material. In situ treatment was eliminated because other more common and effective remedial technologies are available. In particular, in situ treatment has not been used in areas with propeller scour forces similar to the EW, and there are concerns that AC, which has a lower density than native sediments, may not be stable over the long term.

7.8.4 Sill Reach

The Sill Reach is characterized by shallow bathymetry (-11 to -4 feet MLLW) and a series of three bridges. The Railroad/Emergency Access Bridge is at the southern boundary of the CMA and has limited access from low-clearance support columns and piles. To the north is the West Seattle Bridge, which has fewer access limitations due to the high deck surface and fewer support columns. Access to the area under the West Seattle Bridge is limited by the low spans of the bridges to the north and south of the West Seattle Bridge; mobilization of equipment and materials would likely need to be from the uplands. The bridge at the north end of the CMA is the Spokane Street Bridge, which has extremely low clearance and many support piles. MNR, ENR, and in situ treatment were retained for the areas under the low bridges (Railroad/Emergency Access Bridge and the Spokane Street Bridge), with removal and capping eliminated. ENR, in situ treatment, and removal were retained for the West Seattle Bridge area, with capping and MNR eliminated. However, in situ treatment was not incorporated into the alternatives for the West Seattle Bridge area because more common and effective technologies are available (e.g., removal and ENR).

Similar to the underpier areas, MNR was retained for the low bridge areas because of its practicability as compared to other remedial technologies such as removal or placement of a cap, because of the recovery potential following the remediation of adjacent areas, and because of the relatively small area under the bridges (and, therefore, relatively small contribution to site-wide risks). MNR was not retained for the West Seattle Bridge area because it is anticipated that sediments can be accessed for other remedial technologies such as ENR and removal.

ENR was retained for the entire Sill Reach. Because of limited vessel traffic, vessel propwash scour potential is considered low in this area. An ENR layer is anticipated to remain in place and accelerate natural recovery processes. Placement of ENR sand under low bridges would have to be performed in a manner similar to that described above for in situ treatment in underpier areas; placement of ENR sand in the area under the West Seattle Bridge would be staged from the uplands area, should water access be infeasible.

Removal was retained under the West Seattle Bridge, where sediments are anticipated to be accessible without using diver-assisted hydraulic dredging methods. Mobilization and staging would likely occur from the uplands. Removal may not be practicable near bridge columns, as determined during remedial design. Structures are assumed to remain intact during remediation, and contamination left behind due to structural considerations will be addressed as part of residuals management following removal activities. Removal was not retained under the low bridges because it is not technically implementable. Similar to the underpier areas, diver-assisted hydraulic dredging would be necessary due to equipment access limitations. Unlike underpier areas, the low bridges have more consolidated sediment and debris, making it infeasible to remove sediment by diver-assisted hydraulic dredging.

Capping was not retained as a remedial technology in the Sill Reach because the mudline elevation is primarily shallower than the elevation of -10 feet MLLW and, therefore, partial dredging would be required prior to capping for habitat purposes. Partial dredging and capping was not retained because the contamination depth is approximately 3 to 5 feet based on available data; therefore, partial dredging and capping would not be warranted because all or most of contaminated sediment would be removed prior to capping.

In situ treatment was retained in the Sill Reach; however, other more common and effective remedial technologies (i.e., ENR and removal) were incorporated into alternatives for stability and effectiveness considerations. Integration of in situ treatment materials (i.e., AC) into ENR sand and gravel may be considered during remedial design.

7.8.5 Junction Reach

Data indicate that surface sediment and shallow subsurface sediment (0 to 2 feet below mudline) concentrations are below the RAL set that includes a PCB RAL of 12 mg/kg OC; see Section 6); therefore, no remediation will be conducted in the Junction Reach for most alternatives. However, a 0.5-acre area has been identified for remediation for alternatives that use the PCB RAL of 7.5 mg/kg OC. For alternatives with the lower PCB RAL, removal was retained for this CMA. As discussed in Section 7.7, shoreline structures such as piers will limit full removal in some locations, and shoreline structures are assumed to remain intact during remediation.

Partial removal and capping was retained for this CMA. However, there is no alternative that incorporates this technology for this CMA because the partial dredging depth needed to gain clearance for the cap is deeper than the contamination thickness. Therefore, contamination would be removed by required partial dredging, making capping unnecessary in this CMA.

ENR was retained in conjunction with partial removal to gain clearance for future maintenance and navigation activities. However, there are no alternatives that incorporate ENR in the Junction Reach because the alternatives with the PCB RAL of 7.5 mg/kg OC focus on removal.

MNR was retained in the Junction Reach due to the low concentrations of contaminants present. However, there are no alternatives that incorporate MNR in this CMA because the alternatives with the PCB RAL of 7.5 mg/kg OC focus on removal.

In situ treatment was retained in the Junction Reach, however, other more common and effective remedial technologies (i.e., removal) were incorporated into alternatives for stability and effectiveness considerations. The use of in situ treatment materials (i.e., AC) may be considered during design.

7.8.6 Former Pier 24 Piling Field

The Former Pier 24 Piling Field CMA is a nearshore area with numerous old piles in poor condition. This FS assumes that pile removal will be a necessary component of any remedial action in this area. Removal, capping (with partial dredging), and ENR (with pile removal) were retained for this CMA, and in situ treatment and MNR were eliminated.

Removal was retained for this CMA for the reasons summarized in Section 7.2.6.6. Because the CMA is shallower than -10 feet MLLW, the area will be backfilled to grade following removal for habitat purposes. This area is targeted for habitat restoration following remediation.

Capping was retained in conjunction with partial removal to preserve elevations for habitat purposes as described in Section 7.2.5.3. Partial dredging depths are assumed to be equivalent to the cap thickness.

ENR was retained in conjunction with pile removal for this CMA. Piles could be pulled or cut at mudline prior to placement of ENR. ENR material would be placed at a stable grade (e.g., 3H:1V) and be used in areas with moderate contaminant concentrations. Although ENR is retained for consideration during design, ENR is not incorporated into the remedial alternatives because of the potential for high concentrations in surface sediment following pile removal.

MNR and in situ treatment were eliminated for this CMA due to the potential for high contaminant concentrations following pile removal.

7.8.7 Nearshore Areas not Used as Berths

Nearshore areas not used as berths include T-25 Nearshore, T-30 Nearshore, Slip 27 Nearshore/Mound Area, and Coast Guard Nearshore. All of these CMAs include nearshore sediments and accessible sloped banks. Removal was retained for T-25 Nearshore and T-30 Nearshore, with capping, ENR, MNR, and in situ treatment eliminated. Capping (with partial dredging) was retained for Slip 27 Nearshore/Mound Area and Coast Guard Nearshore with removal, ENR, MNR, and in situ treatment eliminated.

Removal was retained for T-25 Nearshore and T-30 Nearshore for the reasons summarized in Section 7.2.6.6. Engineered shorelines could limit full removal in some locations. Areas shallower than -10 feet MLLW will be backfilled to grade following removal for habitat purposes. Removal was eliminated for the Slip 27 Nearshore/Mound Area and the Coast Guard Nearshore because they have cores exhibiting deep contamination (13 feet thick or greater for both CMAs) and engineered shorelines, making full removal impracticable.

Capping was retained in conjunction with partial removal for Slip 27 Nearshore/Mound Area and the Coast Guard Nearshore to preserve elevations for habitat purposes as described in Section 7.2.5.3. Partial dredging depths are assumed to be equivalent to the cap thickness in areas shallower than -10 feet MLLW. Capping was not retained for T-25 Nearshore and T-30 Nearshore CMAs because they have thinner contamination (approximately 5 feet or less for both areas); therefore, most contamination would be removed by partial dredging, making capping unnecessary.

MNR and ENR were eliminated for these CMAs due to the concentrations in surface sediment and/or slope stability requirements. In situ treatment was also eliminated because other more common and effective remedial technologies are available.

7.8.8 Communication Cable Crossing

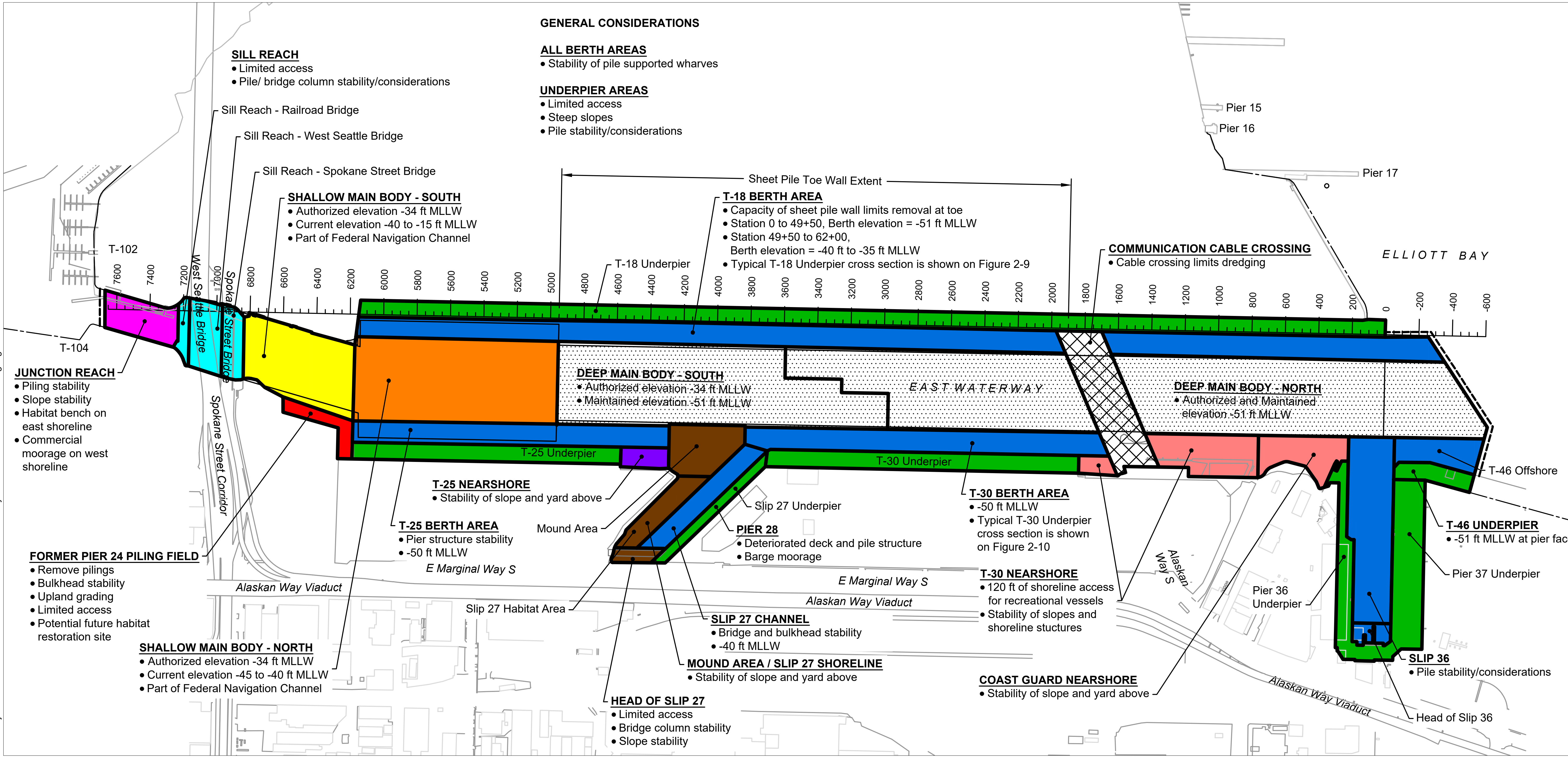
The Communication Cable Crossing CMA traverses the EW OU at Stations 1400 to 2000. Portions of the CMA are in the federal navigation channel and berth areas and, therefore, have navigation elevation requirements. Removal and ENR (with partial dredging) were retained for these areas; capping, MNR, and in situ treatment were eliminated.

The limits of removal will need to be restricted to avoid damage to the communication cable and supporting infrastructure (i.e., rock ballast structure). For this reason, the removal alternative is referred to as "removal to the maximum extent practicable and backfill." Backfill is intended to provide additional protectiveness for any buried contamination left behind; sufficient clearance may not be present to construct a full isolation cap. Backfill may not be necessary if all or most contamination is removed in this area, as determined during design.

ENR was retained in conjunction with partial removal in this CMA to gain appropriate clearance to achieve authorized navigation depths. Similar to the adjacent Deep Main Body – North CMA (Section 7.8.1), ENR was incorporated into the remedial alternatives as ENR-nav, which would include additional measures to mitigate the impact of vessel scour on surface sediment chemistry. For this FS, it is assumed to be a thicker layer of ENR (average thickness of 18 inches as opposed to 9 inches in other ENR areas), which would mitigate the impact of scour by increasing the scour depth necessary to impact underlying sediment and increase the mass of clean sediment to mix with underlying sediment. Furthermore, this FS assumes that ENR-nav would only be employed in areas with relatively low sediment concentrations (e.g., between RALs and 2x RALs) to further reduce the impact of potential mixing of ENR-nav material with underlying sediment.

Capping was not retained in this CMA because the communication cable crossing structure limits partial removal depth required to gain navigational clearance once a full cap was placed.

MNR was eliminated in this CMA due to the potential for resuspension of surface and subsurface contaminated sediment from erosive forces such as propwash, and because future maintenance dredging could remove newly deposited sediment. In situ treatment was also eliminated because other more common and effective remedial technologies are available. In particular, in situ treatment has not been used in areas with propeller scour forces similar to the EW, and there are concerns that AC, which has a lower density than native sediments, may not be stable over the long term.



HORIZONTAL DATUM: Washington State Plane North, NAD83.

NOTES:
1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. Figures 2-9 and 2-10 provide typical underpier cross sections for T-18 and T-30, respectively.

LEGEND:

- East Waterway Study Boundary
- MHHW line
- Construction Management Areas
- Deep Draft Berth Areas
- Underpier Areas
- Deep Main Body
- Junction Reach
- Sill Reach
- Shallow Main Body - South
- Shallow Main Body - North
- Mound Area/Slip 27 Shoreline
- T-25 Nearshore
- T-30/Coast Guard Nearshore
- Former Pier 24 Pile Field
- Communication Cable Crossing

0 600
Scale in Feet

Figure 7-1
Critical Site Restrictions by Construction Management Area
Feasibility Study
East Waterway Study Area

K:\Projects\0003-Port of Seattle\POS SD-101 East Waterway SRI-FS\0003-RP-005-CMA.dwg Figure 7-1
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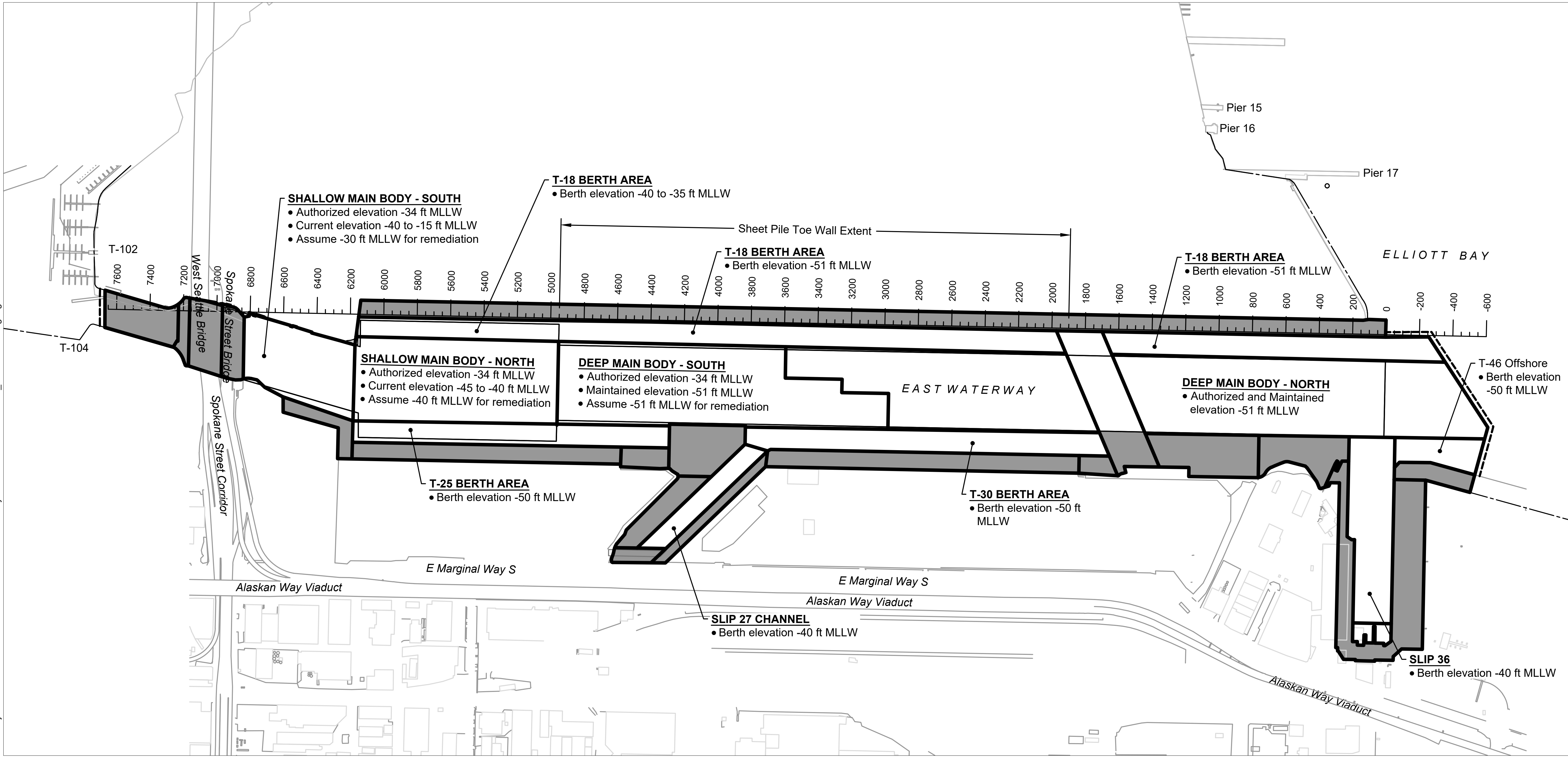

K:\Projects\0003-Port of Seattle\POS SD-101 East Waterway SRI-FS\0003-RP-011-Nav_Berth Elevs.dwg Figure 7-2

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HORIZONTAL DATUM: Washington State Plane North, NAD83.

NOTES:
1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. Figures 2-9 and 2-10 provide typical underpier cross sections for T-18 and T-30, respectively.
3. In the Shallow Main Body- South, the navigation channel may require reauthorization or deauthorization (depending on the alternative) because the remediation elevation is higher than authorized navigation elevation. See description of alternatives in Section 8.

LEGEND:
- East Waterway Study Boundary
- MHHW line
- Construction Management Areas (CMA)
- CMA Not in Navigation Channel or Berthing Area

0 600
Scale in Feet

N

Figure 7-2
Navigation and Berth Elevations
Feasibility Study
East Waterway Study Area

8 DEVELOPMENT OF REMEDIAL ALTERNATIVES

This section presents the assembly and description of alternatives for cleanup of the EW OU. The alternatives are assembled in a manner consistent with CERCLA guidance (EPA 1988). With the exception of the No Action alternative, each of the alternatives is designed to achieve the PRGs, or as close as practicable to the PRGs[89] (the performance of the alternatives is discussed in detail in Section 9). All other alternatives are referred to as the "action alternatives."

The preliminary alternatives were assembled and screened in coordination with EPA, as presented in Appendix L. The alternatives are based on the RALs and remediation footprints developed in Section 6 and the remedial technologies (applicable to CMAs) retained in Section 7, with the objective of screening a wide range of technically feasible options and a variety of remedial technologies. The preliminary alternatives in Appendix L were screened for effectiveness (both long- and short-term), implementability (from technical and administrative feasibility perspectives), and costs per CERCLA guidance. The selected remedial alternatives are described in Section 8.2 and carried forward for detailed and comparative analysis in Sections 9 and 10 of the FS.

Section 8.1 discusses the common assumptions used for the action alternatives, Section 8.2 describes in detail the specific elements of the alternatives, and Section 8.3 discusses key uncertainties in the assumptions used to develop the action alternatives.

8.1 Common Elements for all Action Alternatives

This section provides assumptions used in the development of the action alternatives. It includes common engineering assumptions (Section 8.1.1), technology-specific engineering assumptions (Section 8.1.2), remedial design investigations and evaluations (Section 8.1.3), monitoring (Section 8.1.4), adaptive management (Section 8.1.5), and project sequencing (Section 8.1.6).

[89] Applies to PRGs based on natural background sediment concentrations.

8.1.1 Engineering Assumptions

8.1.1.1 Staging

Staging for sediment remediation projects refers to upland operational areas that support material and equipment handling to and from the in-water project location. Upland staging areas are required to support equipment and material transfers to barges, transloading of dredged sediment for upland disposal, and land-based excavation operations.

For planning purposes, this FS assumes that suitable land will be available in the vicinity of the EW OU for staging and support activities. Specific staging areas have not been identified, and only rough assumptions have been made about specific staging area requirements. The cost estimate in Appendix E assumes that staging activities are incorporated into the mobilization/demobilization and site preparation costs for the project.

8.1.1.2 Pile and Debris Removal

The FS assumes that most dolphins, piles, and in-water structures will remain in place during remediation. Offsets will be needed adjacent to these structures to avoid any structural damage or impacts to structure stability. The offset requirements will be determined during remdial design. However, derelict piling and piers may be removed during remediation as determined during remedial design. Piles in removal areas will be extracted before dredging or removed during dredging. Piles in partial dredging and capping areas may be fully removed or partially removed and covered with an engineered cap as determined in design. For cost estimating, all action alternatives assume that 1,000 piles will be removed from the waterway, which is the approximate number of piles in the Pier 24 Piling Field (Station 6400 East).

Debris of varying size and spatial density may be present in portions of the EW OU. The amount of debris is not known at this time; however, the amount of debris is likely to be less in areas that have been deepened or maintenance dredged in the last several decades (e.g., portions of the Deep Main Body Reach). Standard practice in environmental dredging operations is to remove or “sweep” for debris (e.g., logs, concrete) concurrent with sediment removal. The debris is then barged and offloaded at a transloading facility for subsequent shipment to an upland landfill or for potential recycling (i.e., beneficial reuse). Side-scan sonar surveys, magnetometer surveys, and other methods may be used to assess the presence of debris. If no debris is detected, a debris removal pass may not be required. Debris removal was incorporated into the cost estimate by considering reduced efficiency during debris removal when estimating the removal production rate (and resultant unit costs). The cost estimate assumes that no debris removal would be necessary in ENR, in situ treatment, or MNR areas. This FS assumes that in situ treatment and ENR material would be effectively placed without removing debris, and debris would not require removal prior to placement. Debris removal could have a large impact on costs and dredging effectiveness, particularly for underpier dredging. Although the amount of underpier debris has not been quantified, significant debris has been observed during maintenance dredging next to piers (e.g., at T-18).

8.1.1.3 Transloading and Upland Disposal

The availability and capacity of transloading and transportation infrastructure to manage dredged material is an important factor in the production or dredging rate. This FS assumes that transloading would occur at a nearby EPA–approved facility, or that a transloading facility would be constructed in the vicinity of the EW OU. Because the availability of an existing transload facility is not assured, costs for the construction and maintenance of a transload facility are included in mobilization costs for the alternatives (Appendix E).

Transloading and transportation could occur by various methods, such as loading directly to rail and then transporting directly to the disposal facility, loading directly to truck and then trucking to the disposal facility, or a combination of truck and rail. Considerations for selecting the location of the transloading facility include proximity to the site and rail, existing infrastructure and site use, throughput capacity, permitting requirements, odor, noise, water management, and navigation restrictions. For calculating short-term effectiveness of the alternatives, Appendix I assumes that contaminated sediment would be barged to a nearby existing or newly constructed transloading facility and sent by rail to a landfill; no additional transportation is assumed to occur at the landfill facility. The estimated cost of $70/ton of sediment includes transloading, water management at a transloading facility, truck transportation to a rail facility, rail transport to a landfill, and offloading and disposal of material to a permitted Subtitle D landfill (see Appendix E). If an existing transload facility is used, then the total transload and disposal costs are expected to be similar to those in the FS cost estimate. In this case, the mobilization costs would go down because the transload facility would not need to be constructed specifically for the EW cleanup, but the unit transloading costs would go up to incorporate up-front costs paid to the entity owning/operating the transloading facility for mobilization, permitting, and land lease.

8.1.1.4 Water Management

For mechanical dredging, this FS assumes that dredged sediment will initially be dewatered on the dredge scows with water discharged back to the EW OU within the dredging area after appropriate on-board processing. It is assumed that the dredge scows will be equipped with appropriate BMPs (e.g., hay bales, weir systems, and filtration) to filter runoff as necessary to maintain compliance with applicable water quality criteria established for the dredging operations. If water quality exceedances occur during remedial activities, construction operations may be suspended until adequate BMPs are in place to achieve water quality criteria. Gravity drainage consolidates the sediment load, reduces potential releases during offloading, and reduces the volume of water that otherwise would need to be managed elsewhere (e.g., transloading facility or landfill). Water management costs (per the methods outlined above) during mechanical dredging are included in the unit cost for dredging of $27/cy. As described in Section 7.5.1.1, water quality criteria at recent dredging projects (EW T-18 Maintenance Dredging and the LDW Slip 4 and T-117 EAAs) have been met using gravity dewatering through filter media. However, additional treatment of dewatering effluent may be considered during remedial design. If gravity dewatering is not allowed at the site, water treatment costs will be higher and dredging production rates will be lower.

For underpier diver-assisted hydraulic dredging, this FS assumes that water management will be performed by constructing a water treatment system on a barge. The water treatment system would consist of a series of tanks and filters to treat dewatered liquid and contaminants from dredged material. Clean water would be discharged back into the waterway. The cost for dewatering of hydraulically dredged sediment is estimated to be $400/cy of sediment.

Water management is also a key component of dredged material transloading operations. Stormwater and drainage from sediments generated within the confines of the transloading facility are assumed to be captured, stored, treated, and either discharged to the local sanitary sewer under a King County Discharge Authorization or returned to the EW. Discharge into the EW must comply with the substantive requirements of the National Pollutant Discharge Elimination System permitting regulations (WAC 173-220), as administered by Ecology.

Several landfills are permitted to receive wet sediment (i.e., that does not pass the paint filter test), including two regional RCRA Subtitle D landfills (Allied Waste Inc. in Roosevelt, Washington and Waste Management in Arlington, Oregon) and another regional landfill permitted to accept wet sediment (Weyerhaeuser Regional Landfill in Castle Rock, Washington). Once transferred to lined shipping containers, any additional consolidation of sediment and corresponding accumulations of free water are managed at the landfill facility.

8.1.1.5 Sea Level Rise

Climate change is expected to continue to increase sea levels over the next few hundred years (NRC 2012; National Assessment Synthesis Team 2000; Ecology 2006), and this is a design consideration for cleaning up high elevation (i.e., nearshore and intertidal) areas of the EW OU. The predicted sea level rise in the vicinity of the EW OU is approximately 4 to 56 inches over the next century, with a mean projection of 24 inches (NRC 2012). Sea level rise would result in a corresponding shift in the elevations that define intertidal habitat and regulatory boundaries. Further, the design of engineered shoreline infrastructure (e.g., shoreline caps) may need to address the long-term effects of sea level rise. Sea level may factor into certain remedial design elements in intertidal areas, but is not considered to be a significant factor in the selection or the analysis of the alternatives in this FS since it will likely impact all alternatives equally.

8.1.1.6 Dredge Area and Volume Estimates

The area requiring remediation is based on samples with surface and shallow subsurface sediment concentrations exceeding the alternative's RALs. The method for determining the area requiring remediation is presented in Section 6.

Removal and placement volumes are key parameters for estimating costs and construction durations for the alternatives. The method for estimating removal volume in each area is detailed in Appendix F. The general approach for estimating removal volume was to estimate the thickness of sediment above the appropriate RAL set at every core location to establish an estimated neatline for the dredge prism for each RAL set. The neatline volume was calculated in CAD by multiplying neatline dredge depth by area for removal areas. Total removal volumes were then estimated by multiplying the neatline volume by a constructability factor of 1.5 (in most areas) to include provisions for stable dredge cut side slopes, allowable over-depth, slumping of sediments between dredge units, and missed inventory (Palermo 2009). Note that dredging to remove contaminants exceeding RALs (for any of the RAL sets) would also remove all contaminants exceeding SQS based on existing core data.

The approach to estimating neatline volume varied depending on location in the EW OU. In the Deep and Shallow Main Body Reaches and adjacent berthing areas (T-18 Berthing Area, T-25 Berthing Area, and T-30 Berthing Area), the neatline volume of contaminated sediment was estimated by interpolating with a triangular irregular network (TIN) based on the contaminated thickness of the appropriate RAL set at the location of each core in CAD. Further refinement of the TIN will be completed during remedial design to develop the dredge prism.

The neatline volumes for smaller open-water CMAs (i.e., Sill Reach, Former Pier 24 Piling Field, T-25 Nearshore, Mound Area, Slip 27 Channel, T-30 Nearshore, T-46 Offshore, and Slip 36) were established by estimating a contaminated thickness based on cores in and near the CMAs, and multiplying by area. As discussed in Appendix F, the TIN was not used in these smaller, open-water CMAs because the assumed contaminated sediment thickness at the MHHW boundary would have a larger effect on volumes than actual core data, therefore making the TIN less accurate.

In the Mound Area, Slip 27 Head and Shoreline, and the Coast Guard Nearshore CMAs, the dredging depth was assumed to be 5 feet for the FS (plus the constructability factor of 1.5 to account for overdredging, etc.), to accommodate a 5-foot cap while restoring the surface elevations to the existing grade.

Due to uncertainties with existing conditions in the Communication Cable Crossing CMA because of lack of as-built or cable survey information, the neatline volume assumes a sediment thickness of 3 feet to the top of the cable's armored trench, multiplied by the associated dredging area. Additional surveys of this area will be required during remedial design.

The neatline volumes in underpier areas were estimated by analyzing underpier cross sections using jet probe data. The jet probe data were collected during underpier surveys in 1998 and 2000 at T-18, T-25, and T-30 to measure the lateral extent of sediment in underpier areas and sediment thickness along transects (Sunchasers 2000). Estimations were made of the cross-sectional area of soft sediment for cross sections along the piers. The cross-sectional area of soft sediment was multiplied by the representative pier length to estimate the total volume of soft sediment. The area of riprap without sediment was removed from the potential remediation area. Finally, the cross-sectional area of sediment was assumed to be the same, resulting in an assumed uniform average thickness of 2.3 feet of sediment. The area above RALs in underpier areas was estimated based on Thiessen polygons, which include polygons associated with underpier samples and adjacent open-water samples (see Appendix F for additional detail).

8.1.1.7 Material Placement Volume Estimates

The placement volumes were calculated by the following assumptions:

- RMC was assumed to be applied as a 9-inch average thickness over all open-water dredging areas plus the interior unremediated areas (i.e., the open-water unremediated areas surrounded by dredging areas; see Figure 6-6). A 9-inch thickness has been demonstrated to be effective at other sites for RMC and anti-degradation cover, and is expected to be effective in the EW considering estimates of site-specific dredge residuals (see Appendix B, Part 5). RMC is assumed to be placed for costing purposes, but is contingent on post-dredge sampling and monitoring results.
- Backfill to original grade was assumed to be applied to all open-water dredging areas shallower than -10 feet MLLW, and to the Communication Cable Crossing. The backfill volume was assumed to equal the dredging volume in these areas. Areas shallower than -10 feet MLLW are assumed to be returned to grade to preserve

shallow water areas that serve as important habitat; alternative post-construction elevations may be selected in design to preserve or increase habitat value. In the Communication Cable Crossing CMA, the thickness of backfill will be re-evaluated during design and will be dependent on the practicable dredging depth in the area. For example, if removal of all sediment exceeding RALs is practicable, then backfill may not be necessary, whereas if significant contamination remains in place following dredging, then backfill would be necessary to reduce the chance of recontamination of surface sediment.

- Capping was assumed to be a total of 5 feet thick in all locations, consisting of a 2.5-foot isolation layer, a 1.0-foot filter layer, and a 1.5-foot armor layer. This is a reasonable capping thickness to be assumed site-wide, based on propwash modeling and contaminant transport modeling (see Appendix D); however, the cap thickness may be refined during remedial design, based on location–specific conditions.
- ENR in the Sill Reach (outside of navigation and berthing areas (ENR-sill) was assumed to be applied as a 9-inch average thickness of sand, similar to RMC.
- ENR inside of navigation and berthing areas (ENR-nav) was assumed to be applied as an 18-inch average thickness of sand.
- In situ treatment was assumed to be applied in underpier areas in a 3-inch thickness (consistent with the Bremerton pilot study (see Section 7.2.7.1), with an appropriate percent of AC (between 2% and 5%) to mix into the bioturbation zone, as determined during remedial design.

8.1.1.8 Construction Timeframe

The Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15 (USACE 2015). However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15, to avoid conflicts with tribal netfishing, potential adverse effects to migrating salmon, and for consistency with commonly accepted construction window of upstream waters (i.e., the LDW construction window is October 1 to February 15). The FS conservatively estimates that the total number of construction days for a typical construction season is 100 days/season. This estimate accounts for 37 non-construction days, consisting of weekends, holidays, and down time within the October 1 to February 15 timeframe. Tribal netfishing does occur later than

October 1 and will require tribal coordination of construction timing, which could further shorten the timeframe assumed. It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15); however, a coordination plan between the potentially responsible parties, EPA, and affected tribes may be necessary in order to reduce possibilities of construction activities needing to be stopped during the tribal netfisheries. With this longer construction window, the upper end of the number of work days in a construction season could increase to around 150 days/season. Any realized increase in the construction window between 100 to 150 days per year would reduce the total number of construction years by approximately 2 years for all the action alternatives.

The FS assumes that open-water work would be performed in one 12-hour shift per day, and underpier work would be performed in one 8-hour shift per day. The dredge production rate in the EW is limited by a number of constraints including available transloading infrastructure, the need to work around active port operations (i.e., berthed and navigating vessels), and stringent water quality requirements.

Detailed phasing for the EW cleanup will be determined during remedial design. For the FS, the construction timeframe calculation assumes that one open-water operation and one underpier operation would operate concurrently. Following several seasons of removal, placement operations (capping, ENR, or in situ treatment) could happen concurrently with dredging operations, assuming that sufficient distance and controls would be used to avoid contamination from dredging residuals (e.g., if dredging operations start in the south part of the site and move northward, then capping, ENR, and in situ treatment placement could occur in the south portion of the site while dredging occurs in the north portion of the site). Finally, RMC placement is assumed to occur throughout the waterway following all dredging and other placement operations to minimize potential recontamination of RMC during construction (Appendix E).

The average production rates for various activities for construction timeframe estimates are as follows (basis presented in Appendix E):

- Open-water dredging: 1,100 cy/day
- Limited access dredging (under the West Seattle Bridge): 270 cy/day

- Underpier dredging: 40 cy/day
- Sand and gravel placement (capping isolation and filter layers, ENR, RMC): 940 cy/day
- Cap armor placement: 560 cy/day
- Underpier and low bridge placement (in situ treatment and ENR): 60 cy/day

8.1.2 Technology-specific Engineering Assumptions

This section presents the assumptions that were used in applying each remedial technology for the purpose of estimating cleanup timeframes and costs for this FS. Uncertainties associated with performance of remedial technologies and a discussion of how these uncertainties have been addressed in this FS are included in Section 8.3.

8.1.2.1 Removal

Removal technologies used in the FS rely on different mechanical equipment in open-water areas and diver-assisted hydraulic dredging under piers. These technologies are described below.

Mechanical Dredging

For this FS, mechanical dredging using a clamshell dredge mounted on a derrick barge is assumed in all open-water areas. In difficult-to-access areas (e.g., West Seattle Bridge), alternate removal methods such as excavation using upland equipment could be considered. Mechanical dredging in open-water areas is assumed to cost $27/cy based on recent project experience, assuming $30,000/day for equipment and labor and a production rate of 1,100 cy/day. This estimate includes barge dewatering and delivery of contaminated sediment to the transload facility. Barge sizes vary, but a typical barge for a project conducted in the EW would have a maximum capacity of about 2,000 tons (3,000 cy). The turnaround time for transport, offload, and return to the dredge site could be several days, depending on the location of the offloading facility.

Dredging under the West Seattle Bridge would be more expensive due to lack of access from the water and limited space for maneuvering. The cost for dredging in this location was assumed to be $119/cy to account for limited production rates and trucking to the transload facility.

In practice, the dredging near piers, engineered slopes, the cable crossing, and other structures may not be able to remove all contaminated sediment without compromising structures or slopes. Therefore, the FS assumes that dredging in areas adjacent to piers and slopes would occur to the maximum extent practicable, and remaining contamination would be addressed as part of residuals management.

Diver-assisted Hydraulic Dredging Under Piers

Dredging of underpier areas will have access limitations that preclude the use of traditional marine-based dredging or barge-mounted excavation equipment. In these areas, removal is assumed to be performed by diver-assisted hydraulic dredging since mechanical dredging may pose unacceptable risks for damaging the existing structures and/or underpier riprap slopes.

Removing contaminated sediment from underpier locations presents significant engineering and construction challenges from the stability of piles, potential presence of debris, hard surfaces, or engineered slopes (e.g., riprap). It is not possible to remove 100% of the contaminated sediment from underpier areas because contaminated sediment is present in the interstices of engineered riprap slopes. Furthermore, as discussed in Section 7.2.6.3, diving presents worker safety challenges; the risks for injury and death during construction increase with every hour of diver assistance for hydraulic dredging activities. Underpier areas are adjacent to active berthing areas and diving schedules are likely to be significantly impacted by waterway activities. Similarly, some business interruption will occur as a result of diver-assisted hydraulic dredging because of restricted access to areas where divers are performing underwater work.

The costs for diver-assisted hydraulic dredging are estimated to be $600/cy based on $24,000/day for equipment and labor at a production rate of 40 cy/day, not including water management and treatment. There is high uncertainty in this unit cost; recent project experience shows that costs can be as high as $1,100/cy. Hydraulic dredging also generates a large amount of water requiring treatment. As previously discussed in Section 8.1.1.4, costs for dewatering hydraulically dredged sediment are approximately $400/cy. Mobilization and demobilization costs for dredging and dewatering equipment, diving equipment, and diver safety plans and procedures are estimated to be $250,000 per construction season.

Dredge Residuals Management

As discussed in Section 7.2.6.5, dredging residuals include undisturbed residuals (missed inventory) and generated residuals (re-suspended during dredging).

Dredging typically releases contaminated sediment (referred to as residuals) that settles back onto the dredged surface or is transported outside the dredged area (USACE 2008b; Bridges et al. 2010; Patmont and Palermo 2007). Depending on location-specific conditions, these residuals will contain elevated concentrations of risk driver COCs. To manage residuals, numerous design and operational controls will be evaluated during remedial design.

As discussed in Section 8.1.1.7, residuals management is assumed to include thin-layer placement of 9 inches average of RMC sand layer to address elevated post-dredge concentrations, which could also act as a habitat enhancement layer. During construction, this layer will be placed in areas where post-dredge monitoring shows surface sediment concentrations are above action levels, either in the removal footprint (remediated area) or unremediated area. This RMC sand layer would also serve as anti-degradation cover to comply with the substantive requirements of the state's SMS antidegradation policy (WAC 173-204-120), as necessary. For project sequencing, RMC placement is assumed to occur following all removal and placement activities. RMC is assumed to cost $20/cy for sand purchase and $26/cy for placement, consistent with recent project experience.

Addressing undisturbed residuals is important for achieving dredging goals. Undisturbed residuals will be investigated during post-dredge sampling and addressed as part of contingency actions, such as re-dredging or RMC placement. Additional dredge passes may also be used as part of residuals management. The need and rationale for additional dredge passes will be determined during design, taking into account pre- and post-dredge sediment sampling data and other residual management strategies (e.g., RMC).

8.1.2.2 Partial Dredging and Isolation Capping

For this FS, construction of conventional caps using appropriate material gradations (isolation layer, filter layer, and armor layer) has been assumed. The gradation of material selected for capping depends on factors such as habitat, erosion, and scour potential. Based on preliminary cap modeling in Appendix D, a 5-foot-thick cap has been assumed, representing 1.5 feet of armor, 1 foot of filter material, and 2.5 feet of isolation material. The EW OU is an active waterway used by large vessels with relatively large propwash forces, which may require the use of armoring in many locations. The cap design will be further refined in remedial design, and could include the use of thinner caps amended with sorptive or reactive materials where needed to meet breakthrough performance requirements, refinement of location-specific propwash forces and armoring needs, and a surface habitat layer to support benthic organism and fish communities.

The assumed restrictions on capping associated with water depths in the navigation channel, berthing areas, and habitat areas are provided in Section 7.6. Analysis of the EW OU shows that most areas would require partial dredging prior to capping to comply with elevation requirements. Partial dredging would be performed in the same manner as dredging (previously described in Section 8.1.2.1), with cap placement serving as the RMC. The partial dredging depths are described in Section 7.6.

A key consideration for partial dredging and capping is the amount of dredging required to accommodate a cap with enough post-construction vertical clearance to allow for future maintenance dredging in navigation areas. In one area (Shallow Main Body – South [Stations 6200 to 6850]), the currently authorized navigational depth may not be operationally required based on current and anticipated future site use. Therefore, an option to construct the top of the cap above the currently authorized elevation is included in the FS. This would require a change to the authorization of the federal navigation channel. Reauthorization to -30 feet MLLW is assumed for partial dredging and capping in this FS, but actual depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process. Reauthorization would be initiated after the ROD in conjunction with remedial design to obtain reauthorization prior to capping the Shallow Main Body – South.

Cost assumptions for capping assume that material from a local quarry is transported by barge to the site. For the filter and isolation layers, capping is assumed to cost $20/cy for material purchase and $26/cy for placement. For the armor layer, capping is assumed to cost $35/cy for material purchase and $43/cy for placement, consistent with recent project experience.

8.1.2.3 In situ Treatment

In situ treatment, as described in Section 7.2.7.1, is the placement of an amendment material such as AC to reduce the bioavailability of contaminants in sediments. The amendment material is often placed as part of a clay, sand, and/or gravel matrix to deliver the amendment to the sediments in a reasonably stable lift. In situ treatment is considered for underpier areas because it includes a relatively small thickness of placement material (i.e., less than ENR or an isolation cap) and, therefore, is appropriate for access-limited areas and areas with steep slopes and pile stability considerations.

This FS assumes that in situ treatment would be performed similar to the underpier areas of the Bremerton Naval Shipyard (see Section 7.2.7.1). In this case, a 3-inch-thick layer of material (to produce between 2% and 5% AC in the top 10 cm) was placed via a Telebelt®. The cost for in situ treatment under piers is assumed to be $500/cy for material purchase (e.g., AquaGate+PAC™ composite aggregate system) and $400/cy for placement based on the Bremerton Naval Shipyard Pilot (0.5 acre), with adjustments made for economy of scale for the larger EW underpier areas (12 to 13 acres of in situ treatment area, depending on the alternative).[90]

The effectiveness of in situ treatment depends on multiple factors, including chemical interactions in sediment and the effect of sources from outfalls and open-water exchange. To account for these uncertainties, 15% of underpier in situ treatment areas are assumed to require additional remediation at $4 million per acre by an unspecified remedial technology. Costs are approximately equal to the base capital cost for diver-assisted hydraulic dredging under piers based on an average neatline dredge depth of 2.3 feet (Appendix F) and the unit

[90] The costs of the Bremerton Naval Shipyard Pilot (Chadwick et al. 2014) were reduced by about 75% for economy of scale.

costs for dredging, water management and disposal (Appendix E), without additional costs for construction contingencies, design, project management, etc.

8.1.2.4 Enhanced Natural Recovery

ENR consists of applying a thin layer of sandy material to accelerate the natural recovery processes of mixing and burial. This FS assumes that ENR outside of navigation and berthing areas (ENR in the Sill Reach, called ENR-sill) would involve spreading an average of 9 inches of sand. ENR inside of navigation and berthing areas (ENR-nav) would involve spreading an average of 18 inches of sand. ENR thicknesses and material specifications would be revisited during remedial design.

Material is assumed to be imported from off site, but could be obtained from local maintenance dredging as discussed for in Section 7.2.5.3. The composition of ENR will depend on additional evaluation during remedial design; it may include habitat mix or scour mitigation specifications to increase sediment stability and enhance habitat, or AC to reduce bioavailability of residual contamination (i.e., designed similar to in situ treatment). However, costs for this FS assume that ENR consists of placement of sand only.

In order to preclude treatment material from being removed during future maintenance dredging operations, partial dredging would be required in some ENR-nav areas to gain sufficient clearance. The clearance would be sufficient to prevent ENR material from being removed during future navigation dredging activities. The assumed restrictions on thin-layer placement and capping associated with water depths in the navigation channel, berthing areas, and habitat areas are provided in Section 7.6. Analysis of the EW OU shows that about half of the areas would require partial dredging prior to ENR-nav placement to attain sufficient clearance for potential future maintenance dredging. Partial dredging prior to ENR-nav placement would be performed in the same manner as dredging, as described in Section 8.1.2.2. The partial dredging depths are described in Section 7.6.

Placement of ENR material in difficult-to-access areas (e.g., low bridge areas of the Sill Reach) would be performed the method previously described for placement of in situ treatment material under piers. ENR is assumed to cost $20/cy for sand purchase, $26/cy for placement in open-water areas, and $400/cy under the low bridges of the Sill Reach.

The effectiveness of ENR depends on multiple factors, including sedimentation rate, concentrations of contaminants of incoming sediment, and sediment stability. To account for these uncertainties, 15% of ENR areas are assumed to require additional remediation at $1 million per acre in open-water areas, and $4 million per acre under low bridges by an unspecified remedial technology (costs are approximate equal to the base capital cost for dredging in these areas based on an average neatline dredge depth of 3.5 feet in open-water areas and 2.3 feet in underpier areas, times the unit costs for dredging and disposal, without additional costs for construction contingencies, design, project management, etc.).

8.1.2.5 Monitored Natural Recovery

MNR uses an intensive monitoring program to track success of achieving set chemical concentration reduction over a set time, and a decision framework for implementing contingency actions if needed (adaptive management; EPA 2005).

As discussed in Section 7.7, MNR was retained in underpier areas and under low bridges for several reasons. First, most other remediation technologies will be challenging to implement under piers; therefore, MNR is significantly more practicable than other forms of remediation. Second, these areas may have high recovery potential following the remediation of adjacent open-water areas because of sediment exchange between these areas. The best estimate used in this FS is that 25% of underpier sediment exchanges with open-water areas every 5 years (see Section 5.3.4). Third, these areas have relatively small spatial extent and, therefore, contribute less to site-wide risks (e.g., see Appendix J sensitivity results for Alternative 1A(12)) from bioaccumulative compounds.

Multiple lines of evidence support the limited areas that are considered for MNR in the FS. Although there were no geochronological cores located directly under the piers and low bridges, geochronological cores from adjacent areas are assumed to be sufficient to estimate sedimentation rates in these areas (Appendix J). In addition, the exchange of underpier sediment with open-water areas is a key consideration for MNR under the piers. The proximity of underpier sediment to berthing operations indicate that underpier sediment is subject to resuspension by propwash forces; however, vessel scour patterns indicate that resuspended sediment from adjacent berthing areas are depositing in the underpier. The estimated sedimentation rates and underpier exchange rates are factored into the estimated effectiveness of MNR presented in Appendix J and Section 9.4.

This FS assumes that area-specific MNR sampling would occur at prescribed intervals (see Appendix G). Adaptive management (i.e., contingency actions) may occur at any time during the monitoring period. Contingency actions for areas that do not achieve RALs may include active remediation, additional investigation, and further monitoring, and are included as separate line items in the cost estimate.

The effectiveness of MNR depends on multiple factors, including sedimentation rate, concentrations of contaminants of incoming sediment, sediment exchange with open-water areas, and sediment stability. To account for uncertainties in these factors, 15% of MNR areas are assumed to require additional remediation at $4 million per acre by an unspecified remedial technology (costs are approximate equal to the base capital cost for dredging under piers and low bridges based on an average neatline dredge depth of 2.3 feet and the unit costs for dredging, water management, and disposal, without additional costs for construction contingencies, design, project management, etc.]).

8.1.2.6 Institutional Controls

The two major types of institutional controls considered for this FS are: 1) proprietary controls, typically as environmental covenants enforceable by EPA or the property owner; and 2) informational devices. Informational devices are further split into two primary components: a) monitoring and notification of waterway users, including the state's Environmental Covenants Registry; and b) seafood consumption advisories, public outreach, and education. These are discussed in Section 7.2.2.

All types of institutional controls apply to all action alternatives. Seafood consumption advisories, public outreach, and education would likely be similar in scope for all action alternatives. Proprietary controls and monitoring and notification of waterway users will vary in scope depending on the amount of contamination left on site. The degree to which each of these institutional controls is expected to be used for each alternative is discussed in Section 8.3.

Costs for institutional controls are incorporated into the cost estimate for each action alternative as part of total project management and agency review/oversight costs, which are assumed to be 1% of total construction costs (project management), and $120,000/year for 25 years following construction for agency review/oversight (Appendix E).

8.1.3 Remedial Design

Remedial design investigations include location-specific sampling or testing for the purpose of refining the design and engineering assumptions for the selected remedy. The EW OU has been studied extensively for the SRI/FS, previous remediation projects, and past development projects. Therefore, much of the information needed for remedial design is already available. However, some additional investigations may be necessary during remedial design to complete the design process, refine the selected remedial technology footprints, and evaluate performance potential. Remedial design investigations may be needed to accomplish the following:

- Refine the nature and extent of contaminated sediment in EW OU being considered for remediation, including the vertical and horizontal extent of contamination above the RALs as needed to inform design.
- Use available data to conduct additional evaluations to calculate anticipated stability of native sediments or placement materials such as sand cover or cap armoring.
- Collect bathymetric data to evaluate current elevations.
- Use sub-bottom surveys to determine the extent of soft sediment on riprap slopes and the extent of riprap keyways.
- Perform geotechnical testing on sediment cores for physical properties to assess, for example, material handling properties and sediment strength for capping as needed.
- Refine remedial technology assignments based on the investigations above.

Appropriate agencies and stakeholders will review remedial design documents. Costs for remedial design are incorporated into the design and permitting line item, which is assumed to be 5% of project construction costs (see Appendix E).

8.1.4 Monitoring

Monitoring is a key assessment technology for sediment remediation. Numerous guidance documents highlight the need for monitoring to verify achievement of project RAOs (EPA 1998, 2005; NRC 2007). For contaminated sediment projects, monitoring can be grouped into five categories (EPA 2005):

- **Pre-construction baseline monitoring –** EW-wide monitoring concurrent with remedial design studies, but separate in design and function
- **Construction monitoring –** Location-specific short-term monitoring during construction to verify performance of the operations
- **Confirmation sampling –** Location-specific performance monitoring immediately following active remediation prior to contractor demobilization
- **Operations and maintenance (O&M) monitoring –** Area- and location-specific monitoring to confirm that technologies are operating as intended (such as MNR)
- **Long-term monitoring –** EW-wide monitoring to confirm that the waterway is making progress toward or achieving the RAOs

The monitoring results from each category inform and direct adaptive management activities to verify long-term remedy implementation and achievement of RAOs. The approximate scope of monitoring for each alternative has been developed in Appendix G based on the remedial areas for each alternative. Each remediation type area was multiplied by sampling unit costs in Appendix G.

8.1.5 Adaptive Management

Adaptive management is the use of data collected during and after remediation to optimize remedial effectiveness. Adaptive management may be used to optimize remedial construction methods and to address remediated areas that may not perform as anticipated. The framework and criteria for adaptive management will be developed in remedial design. Relevant agencies are involved in reviewing adaptive management decisions. Some of the ways that adaptive management may affect the implementation of specific remedial technologies are discussed below.

In dredging and partial dredge and capping areas, data collected during construction monitoring may be used to more effectively employ BMPs while performing remediation to reduce short-term environmental impacts. Post-construction performance monitoring provides information on whether RALs were achieved, which could identify the need for managing dredge residuals. In capping areas, O&M monitoring could identify and assess cap stability and effectiveness and the need to modify the cap.

In MNR, ENR, and in situ treatment areas, O&M monitoring will be used to assess whether RALs have been successfully achieved over the required timeframe. Monitoring in these areas will be used to track the performance of natural recovery in the specific area being remediated and may inform the need for contingency actions.

The long-term monitoring program will include provisions for specific monitoring activities following a disruptive event such as an earthquake, to assess potential impacts and to develop appropriate response actions.

To account for potential contingency actions under the adaptive management framework, 15% of MNR, ENR, and in situ treatment areas are assumed to require additional remediation at $1 million per acre in open-water areas, and $4 million per acre under piers and low bridges. These costs are approximate equal to the capital cost for dredging these areas (i.e., base costs without additional costs for construction contingencies, design, project management, etc.).

8.1.6 Project Sequencing

The project should be sequenced so as to reduce the chance of recontamination from releases during dredging and from uncontrolled sources. For the purpose of estimating the construction timeframe for the action alternatives it was assumed that dredging would be phased before placement in all locations, and that placement operations (i.e., capping, ENR, and in situ treatment) at one end of the waterway could take place concurrently with dredging operations at the other end of the waterway. RMC was assumed to be placed after all other remedial activities are complete. During design, project sequencing may also consider other factors, such as dredging areas with higher concentrations prior to those with lower concentrations, to minimize the impact of releases from dredging in the later stages of the project.

In accordance with EPA guidance and prudent practice, remedial actions generally should not commence until appropriate source control measures have been implemented and their performance verified. Source control programs are ongoing in the EW and are not anticipated to affect the sequence of remediation in the waterway. In certain cases, source control may be the limiting factor in scheduling portions of the in-water cleanup. Timing of source control and remediation efforts upstream of the EW OU (e.g., in the LDW) may also be considered when scheduling remediation of the EW OU.

The EW is an active navigation channel with multiple container terminals that operate 24 hours per day and 7 days per week. Implementation of remediation may require sequencing to accommodate operational needs at the terminals and navigational needs of vessels coming and going from the waterway. In particular, the dredging production rates are assumed to incorporate the need for dredge operations to work around berthed and navigating vessels. In open-water areas, it is assumed that vessel traffic will not significantly impact the dredging rate for a single operation. All underpier areas, however, are adjacent to active berthing areas, and diving schedules are likely to be significantly impacted by waterway activities.

Tribal netfishing in the EW OU will also be considered in establishing project phasing and sequencing. The estimated construction window is shorter than the standard fish window to accommodate tribal netfishing activities in the EW OU; however, even within the specified construction window, tribal fishing may affect the movement of barges, equipment, and work locations.

8.2 Detailed Description of Alternatives

The remedial alternatives selected in Appendix L for detailed and comparative analysis in Sections 9 and 10 of the FS are: 1A(12), 1B(12), 1C+(12), 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), 3E(7.5), and the No Action alternative. As noted above, Alternatives 1A(12) through 3E(7.5) are referred to as the "action alternatives."

The key variables used for developing the remedial alternatives are the remedial technologies (discussed in Section 7) and the RALs (discussed in Section 6), as described in the following sections.

8.2.1 Remedial Technologies

Representative remedial technologies retained following screening in Section 7 form the basis for the alternatives. These alternatives include both active remedial technologies (i.e., removal, capping [with partial removal as necessary], ENR-nav [with partial removal as necessary], ENR-sill, and in situ treatment), and passive remedial technologies (i.e., MNR, site-wide monitoring, and institutional controls). Section 7.7 describes the CMAs and the CMA-specific selection of remedial technologies based on the elevation constraints, sediment stability, and practicability.

The CMAs are grouped into "open-water," which are areas with relatively unrestricted access for remediation, and "limited access areas," which are areas that are difficult to access with typical remediation equipment, and include both the underpier areas and the low bridge areas of the Sill Reach (see Figure 7-1). The open-water remedial technologies are discussed in Section 8.2.1.1, and the limited access area remedial technologies are discussed in Section 8.2.1.2.

As discussed in the Screening Memo (Anchor QEA 2012a) and Section 7, removal forms the basis of all action alternatives due to elevation constraints for navigation and high forces from propwash in the Deep Main Body Reach and berthing areas of the waterway. Removal and partial removal are performed on between 60% to 70% of the site (and 80% to 99% of the remediation area) for all action alternatives.

8.2.1.1 Open-water Remedial Technologies

The open-water CMAs were combined into four groups (Navigation Channel and Berth Areas, Shallow Main Body, Nearshore, and West Seattle Bridge) based on similar structural, waterway use, habitat, and water depth conditions, which result in a different set of potentially applicable remedial technologies. Based on the retained remedial technologies within these groups of CMAs, three technology options are presented to form the basis of the remedial alternatives. The technology options are ordered from the smallest to the largest removal area (all technology options rely primarily on removal due to the navigation depth requirements in the EW). Table 8-1 presents the three open-water technology options (1 through 3) retained in the four open-water CMA groups.

8.2.1.2 Limited Access Area Remedial Technologies

The limited access areas include the underpier CMAs and the two low bridge CMAs in the Sill Reach. These CMAs were divided into two limited access CMA groups based on similar structural, waterway use, habitat, and water depth conditions. Limited access areas present particular challenges for remediation and, as such, have a wider range of technology options than open-water CMAs. Based on the retained remedial technologies within these CMA groups, four technology options, which are referred to as “limited access area technology options” for simplicity, are presented to form the basis of the remedial alternatives. Note that the non-sequential lettering of these options (e.g., no option D) is due to some options being screened out in Appendix L. Table 8-2 presents the four technology options for the two CMA groups.

8.2.2 Remedial Action Levels

RALs, the point-based concentrations above which sediment is remediated, were the second key variable in the alternative assembly. Table 6-1 and Section 6.2 present the RALs; alternatives with two different PCB RALs (12 and 7.5 mg/kg OC) were carried forward into Section 8 to provide a range of remediation footprints for the detailed analysis and comparison of alternatives. The two RAL sets used for remedial alternatives are shown in Table 8-3.

Table 8-1
Open-water Technology Options

Open-water Technology Option	Navigation Channel and Berth Areas (110 acres)	Shallow Main Body (22 acres)[a]	Nearshore (8 acres)[a]	West Seattle Bridge (2 acres)[a]
	CMAs: – *Federal Navigation Channel – South* – *Federal Navigation Channel – North* – *Deep Draft Berth Areas (T-18, T-30, T-25)* – *Slip 27 Channel* – *Slip 36/T-46 Offshore* – *T-25 Nearshore* – *T-30 Nearshore* – *Junction Reach* – *Communication Cable Crossing*	*CMAs:* – *Shallow Main Body – North and South* – *Former Pier 24 Piling Field*	*CMAs:* – *Mound Area/Slip 27 Shoreline* – *Coast Guard Nearshore*	*CMA:* – *Sill Reach – West Seattle Bridge*
1	• Removal • Partial Removal with ENR-nav • ENR-nav	• Removal • Partial Removal and Cap	• Partial Removal and Cap	• ENR-sill
2	• Removal	• Removal • Partial Removal and Cap	• Partial Removal and Cap	• ENR-sill
3	• Removal	• Removal	• Partial Removal and Cap	• Removal

Notes:
1. Open-water CMAs are shown in Figure 8-1.
2. Remedial technology assignment areas for these options are shown in the appropriate alternative figures (see Figures 8-2 through 8-9).
a. The area for the CMAs represents the total area of the CMAs in that group.
CMA – construction management area
ENR – enhanced natural recovery
T – terminal

Table 8-2
Limited Access Area Technology Options

Limited Access Area Technology Option	Underpier (15 acres)[a]	Sill Reach – Low Bridges (2 acres)[a]
	CMA: *– Underpier areas*	*CMAs:* *– Spokane Street Bridge* *– Railroad Bridge*
A	• MNR	• MNR (subtidal) • ENR-sill (intertidal)
B	• In situ treatment	• ENR-sill
C+	• Diver-assisted hydraulic dredging ***followed by in situ treatment*** for PCBs or Hg > CSL[b] • In situ treatment elsewhere	• ENR-sill
E	• Diver-assisted hydraulic dredging followed by in situ treatment	• ENR-sill

Notes:
1. Limited access area CMAs are shown in Figure 8-1.
2. Remedial technology assignment areas for these options are shown in the appropriate alternative figures (see Figures 8-2 through 8-9).

a. The area for the CMAs represents the total area of the CMAs.
b. The underpier dredging-specific action level for the C+ alternatives was developed for PCBs and Hg because they are the primary contributors of risks to human health and the benthic community (see Section 7.8.2).

CMA – construction management areas
CSL – cleanup screening level
ENR – enhanced natural recovery
Hg – mercury
MNR – monitored natural recovery
PCB – polychlorinated biphenyl

Table 8-3
Remedial Action Levels for Technology Development

RAL Set Denotation	Total PCBs RAL	RAL for Other Chemicals	Area Remediated
(12)	12 mg/kg OC	See Table 6-1 (same for all alternatives)	121 of 157 acres
(7.5)	7.5 mg/kg OC		132 of 157 acres

Notes:
mg/kg – milligrams per kilogram
OC – organic carbon
PCB – polychlorinated biphenyl
RAL – remedial action level

8.2.3 Screening of Alternatives

Sixteen alternatives were selected for screening in coordination with EPA to capture the range of technology options and to support comparison of each of the varied parameters (i.e., RAL, open-water technology group, or limited access area technology group). Results of that screening are presented in Appendix L. Generally, alternatives that did not differentiate from other alternatives in effectiveness and implementability but had larger costs were screened out. The alternatives retained for the detailed and comparative analysis in Sections 9 and 10 are listed below, and shown in Tables 8-4 and 8-5 and Figures 8-2 through 8-10. As a reminder, RALs are the same in all alternatives except for total PCB, which vary as shown in Table 8-4.

Table 8-4
Retained Alternatives and Alternative Key

	Alternatives Key (General Description)		
Retained Alternatives	**Open-water**	**Restricted Access (underpier and low bridges)**	**PCBs RAL**
No Action 1A(12) 1B(12) 1C+(12) 2B(12) 2C+(12) 3B(12) 3C+(12) 2C+(7.5) 3E(7.5)	1 – Removal with capping and ENR where applicable 2 – Removal with capping where applicable 3 – Maximum removal to the extent practicable	A – MNR B – In situ treatment C+ – Diver assisted hydraulic dredging followed by in situ treatment for PCBs or Hg > CSL; In situ treatment elsewhere E – Diver-assisted hydraulic dredging followed by in situ treatment	(12) – 12 mg/kg OC (7.5) – 7.5 mg/kg OC

Notes:
CSL – cleanup screening level
ENR – enhanced natural recovery
Hg – mercury
mg/kg – milligrams per kilogram
MNR – monitored natural recovery
OC – organic carbon
PCB – polychlorinated biphenyl

Table 8-5
Remedial Technology Summary for Alternatives by CMA

Alternative	Open-water CMA Groups				Limited Access CMA Groups	
	Deep Main Body and Berth Areas (110 acres)	**Shallow Main Body (22 acres)**	**Nearshore (8 acres)**	**Sill Reach – West Seattle Bridge (2 acres)**	**Underpier (15 acres)**	**Sill Reach – Low Bridges (2 acres)**
	CMAs: *– Federal Navigation Channel – South* *– Federal Navigation Channel – North* *– Deep Draft Berth Areas (T 18, T-30, T-25)* *– Slip 27 Channel* *– Slip 36/T-46 Offshore* *– T-25 Nearshore* *– T-30 Nearshore* *– Junction Reach* *– Communication Cable Crossing*	*CMAs:* *– Shallow Main Body – North and South* *– Former Pier 24 Piling Field*	*CMAs:* *– Mound Area/Slip 27 Shoreline* *– Coast Guard Nearshore*	*CMA:* *– Sill Reach – West Seattle Bridge*	*CMA:* *– Underpier Areas*	*CMAs:* *– Sill Reach – Spokane Street Bridge* *– Sill Reach – Railroad Bridge*
No Action	No Action	No Action	No Action	No Action	No Action	No Action
1A(12)	Removal / Partial Removal and ENR-nav / ENR-nav	Removal / Partial Removal and Cap	Partial Removal and Cap	ENR-sill	MNR	ENR-sill/MNR
1B(12)	Removal / Partial Removal and ENR-nav / ENR-nav	Removal / Partial Removal and Cap	Partial Removal and Cap	ENR-sill	In situ Treatment	ENR-sill
1C+(12)	Removal / Partial Removal and ENR-nav / ENR-nav	Removal / Partial Removal and Cap	Partial Removal and Cap	ENR-sill	Hydraulic dredging ***followed by in situ treatment*** for PCBs or Hg > CSL / In situ treatment elsewhere	ENR-sill
2B(12)	Removal	Removal / Partial Removal and Cap	Partial Removal and Cap	ENR-sill	In situ Treatment	ENR-sill
2C+(12)	Removal	Removal / Partial Removal and Cap	Partial Removal and Cap	ENR-sill	Hydraulic dredging ***followed by in situ treatment*** for PCBs or Hg > CSL / In situ treatment elsewhere	ENR-sill
3B(12)	Removal	Removal	Partial Removal and Cap	Removal	In situ Treatment	ENR-sill
3C+(12)	Removal	Removal	Partial Removal and Cap	Removal	Hydraulic dredging ***followed by in situ treatment*** for PCBs or Hg > CSL / In situ treatment elsewhere	ENR-sill
2C+(7.5)	Removal	Removal	Partial Removal and Cap	Removal	Hydraulic dredging ***followed by in situ treatment*** for PCBs or Hg > CSL / In situ treatment elsewhere	ENR-sill
3E(7.5)	Removal	Removal	Partial Removal and Cap	Removal	Hydraulic dredging followed by in situ treatment	ENR-sill

Notes:
1. Acres for each CMA represent the entire CMA footprint with sediment including areas below RALs that are identified as not requiring remediation. Areas are rounded to the closest acre.
2. See Figure 7-1 for a map of CMA areas.
CMA – Construction Management Area
ENR – enhanced natural recovery
MNR – monitored natural recovery
RAL – remedial action level
T – Terminal

Taken together, the alternatives present a range of remedial options applicable in the EW OU, based on the CMA-specific screening of remedial technologies in Table 7-4. This range in alternatives provides a range in characteristics (areas, volumes, costs, effectiveness, etc.) so that the alternatives can be compared in subsequent sections of this FS. The technology assignment areas, volumes, and costs for each alternative are described in the following sections.

8.2.4 No Action

This alternative assumes that no remedial actions will occur (Figure 8-1). The No Action alternative is required as part of CERCLA FS evaluation process. It is considered a natural recovery alternative,[91] and the only activity for this alternative is site-wide monitoring.

Note that the No Action alternative includes past remedial actions that have been performed in the water such as the non-time critical removal action (NTCRA) performed in 2005; however, costs for these actions are not included in the cost estimate for the No Action alternative. The FS baseline dataset represents post-NTCRA conditions (i.e., data from dredged areas has been removed as appropriate).

8.2.5 Alternative 1A(12)

Alternative 1A(12) is based on open-water option 1 (Table 8-1): removal with capping and ENR-nav where applicable; limited access option A (Table 8-2): MNR; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-2. Like all the action alternatives, Alternative 1A(12) is removal focused, with removal over 80% of the remediation area (62% of the EW). In comparison with the other action alternatives, Alternative 1A(12) relies the most on natural recovery by using MNR (in limited access areas) and ENR (in the Deep Main Body and the Sill Reach). Alternative 1A(12) also employs capping where practicable (in the Shallow Main Body).

[91] "Natural recovery" is distinct from "monitored natural recovery (MNR)" in this context. MNR includes targeted location-specific monitoring, target concentrations, and contingency actions if target concentrations are not achieved. Natural recovery includes site-wide monitoring only, with no target concentrations or contingency actions if target concentrations are not met.

Alternative 1A(12) includes the following combination of remedial technologies:

- **Open-water Option 1 (Table 8-1):**
  - **Navigation Channel and Berth Area:** Removal, ENR-nav, or partial removal and ENR-nav. The Communication Cable Crossing includes removal to the extent practicable and backfill instead of removal to RAL exceedances to protect the structure.
  - **Shallow Main Body Reach:** Removal or partial removal and capping.
  - **Nearshore:** Partial removal and cap.
  - **West Seattle Bridge**: ENR-sill.
- **Limited Access Option A (Table 8-2):**
  - **Underpier areas**: MNR.
  - **Sill Reach – Low Bridges**: ENR-sill in intertidal areas and MNR in subtidal areas.

Table 8-6 shows the total remedial areas and the estimated volumes, costs, and construction timeframes for the alternatives. Alternative 1A(12) includes 97 acres of removal (including 77 acres of removal, 13 acres of partial removal and capping, 7 acres of partial removal and ENR-nav), 2 acres of ENR-sill, 9 acres of ENR-nav, and 13 acres of MNR (under piers and low bridges). The total removal volume is estimated at 810,000 cy and the total placement volume (capping, ENR, RMC layer, and backfill) is 290,000 cy. The alternative will take approximately 9 years to construct (approximately eight seasons of dredging), at a cost of approximately $256 million. The implementation of construction, institutional controls, monitoring, and adaptive management are described in Sections 7 and 8.1.

8.2.6 Alternative 1B(12)

Alternative 1B(12) is based on open-water option 1 (Table 8-1): removal with capping and ENR-nav where applicable; limited access option B (Table 8-2): in situ treatment; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-3.

Table 8-6
Areas, Volumes, and Costs for Alternatives

	Area (acres)																Volume (cubic yards)			
	Open-water and Under Low Bridges									Underpier										
Alternative	Removal	Removal to the Extent Practicable and Backfill (Communication Cable Crossing Area)	Removal and Backfill to Existing Contours	Partial Removal and Capping	Partial Removal and ENR-nav	ENR-nav	ENR-sill	MNR	Interior Unremediated Area[a]	Exterior Unremediated Area	Hydraulic Dredging Followed by in situ Treatment	In situ Treatment	MNR	Underpier Unremediated	Total Remediated Area	No Action Area	Total Area[b]	Total Removal Volume[c]	Total Placement Volume (capping, ENR, in situ treatment, RMC)	Total Cost[d]	Construction Timeframe (years)
No Action	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**157**	**157**	0	0	$950,000	0
1A(12)	73	3	1	13	7	9	2	1	19	15	0	0	12	2	**121**	36	**157**	810,000	290,000	$256,000,000	9
1B(12)	73	3	1	13	7	9	3	0	19	15	0	12	0	2	**121**	36	**157**	810,000	290,000	$264,000,000	9
1C+(12)	73	3	1	13	7	9	3	0	19	15	2	10	0	2	**121**	36	**157**	820,000	290,000	$277,000,000	9
2B(12)	88	5	1	13	0	0	3	0	19	15	0	12	0	2	**121**	36	**157**	900,000	280,000	$284,000,000	10
2C+(12)	88	5	1	13	0	0	3	0	19	15	2	10	0	2	**121**	36	**157**	910,000	280,000	$297,000,000	10
3B(12)	92	5	3	7	0	0	1	0	19	15	0	12	0	2	**121**	36	**157**	960,000	270,000	$298,000,000	10
3C+(12)	92	5	3	7	0	0	1	0	19	15	2	10	0	2	**121**	36	**157**	960,000	270,000	$310,000,000	10
2C+(7.5)	98	5	1	13	0	0	3	0	15	8	2	11	0	2	**132**	25	**157**	1,010,000	290,000	$326,000,000	11
3E(7.5)	102	5	4	7	0	0	1	0	15	8	13	0	0	2	**132**	25	**157**	1,080,000	270,000	$411,000,000	13

Notes:

a. Interior unremediated areas are sediment areas with no RAL exceedances, but which are surrounded by areas to be remediated. For FS purposes, an RMC layer is assumed to be placed in these areas (see Appendix F for more details).

b. Area does not include locations without sediment (i.e., 19 acres of uncovered riprap) in the Underpier, T-25 Nearshore, and T-30 Nearshore Construction Management Areas.

c. Removal volume is based on the assumptions in Appendix F and include the neatline dredging volume multiplied by a design factor of 1.5, except for underpier areas (which is based on the neatline volume without a design factor because sediment is underlain by riprap).

d. Costs are based on assumptions in Appendix E.

All values are rounded for presentation. Apparent discrepancies in totals are only due to rounding.

ENR-nav – enhanced natural recovery applied in the navigation channel and deep-draft berthing areas

ENR-sill – enhanced natural recovery used in the Sill Reach

FS – Feasibility Study

MNR – monitored natural recovery

RAL – remedial action level

RMC – residuals management cover

Like Alternative 1A(12), Alternative 1B(12) is removal focused, with removal over 80% of the remediation area (62% of the EW). Alternative 1B(12) is the same as Alternative 1A(12), except that it replaces MNR with in situ treatment as a remedial technology in underpier areas.

Alternative 1B(12) includes the following combination of remedial technologies:

- **Open-water Option 1 (Table 8-1):** As described for Alternative 1A(12), above.
- **Limited Access Option B (Table 8-2):**
  - **Underpier areas:** In situ treatment.
  - **Sill Reach – Low Bridges:** ENR-sill

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 1B(12) includes 97 acres of removal (77 acres of removal, 13 acres of partial removal and capping, 7 acres of partial removal and ENR-nav), 3 acres of ENR-sill, 9 acres of ENR-nav, and 12 acres of in situ treatment. The total removal volume is estimated at 810,000 cy, and the total placement volume (capping, ENR, RMC layer, and backfill) is 290,000 cy. The alternative has the same construction timeframe (9 years) as Alternative 1A(12), because in situ treatment would occur concurrently with removal operations. Alternative 1B(12) is estimated to cost $264 million. The implementation of construction, institutional controls, monitoring, and adaptive management are described in Sections 7.2 and 8.1.

8.2.7 Alternative 1C+(12)

Alternative 1C+(12) is based on open-water option 1 (Table 8-1): removal with capping and ENR-nav where applicable; limited access area option C+ (Table 8-2): removal followed by in situ treatment for areas with PCBs or mercury greater than the CSL and in situ treatment elsewhere when exceeds RALs; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-4.

Alternative 1C+(12) is removal focused, with removal over 82% of the remediation area (63% of the EW). Alternative 1C+(12) is the same as Alternative 1A(12), except that it replaces

MNR with in situ treatment and hydraulic dredging followed by in situ treatment as the remedial technologies in underpier areas.

Alternative 1C+(12) includes the following combination of remedial technologies:

- **Open-water Option 1 (Table 8-1):** As described for Alternative 1A(12), above.
- **Limited Access Option C+ (Table 8-2):**
  - **Underpier areas:** Limited removal using hydraulic dredging followed by in situ treatment was selected for areas with PCBs or mercury concentrations exceeding the CSL. In situ treatment (without being preceded by hydraulic dredging) would be applied in other areas exceeding the RALs.
  - **Sill Reach – Low Bridges:** ENR-sill (same as Alternative 1B(12)).

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 1C+(12) includes 99 acres of removal (77 acres of removal, 13 acres of partial removal and capping, 7 acres of partial removal and ENR-nav, 2 acres of hydraulic dredging followed by in situ treatment), 3 acres of ENR-sill, 9 acres of ENR-nav, and 10 acres of in situ treatment. The total removal volume is estimated at 820,000 cy, and the total placement volume (capping, ENR, RMC layer, and backfill) is 290,000 cy. The alternative has the same construction timeframe (9 years) as Alternative 1B(12), because diver-assisted hydraulic dredging would occur concurrently with open-water removal operations. Alternative 1C+(12) is estimated to cost $277 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.8 Alternative 2B(12)

Alternative 2B(12) is based on open-water option 2 (Table 8-1): removal with capping where applicable; limited access option B (Table 8-2): in situ treatment; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-5.

Alternative 2B(12) is removal focused, with removal over 88% of the remediation area (68% of the EW). Alternative 2B(12) is identical to Alternative 1B(12), except that ENR-nav and partial dredging and ENR-nav are substituted by removal of sediment exceeding RALs. Like Alternative 1B(12), Alternative 2B(12) includes partial dredging and capping where practicable in the Shallow Main Body. Alternative 2B(12) includes the following combination of remedial technologies:

- **Open-water Option 2 (Table 8-1):**
  - **Navigation Channel and Berth Area:** Removal. The Communication Cable Crossing includes removal to the extent practicable and backfill instead of removal to RAL exceedances to protect the structure.
  - **Shallow Main Body Reach:** Removal or partial removal and capping (same as described for Alternative 1A(12)).
  - **Nearshore:** Partial removal and cap (same as described for Alternative 1A(12)).
  - **West Seattle Bridge:** ENR-sill (same as described for Alternative 1A(12)).
- **Limited Access Option B (Table 8-2):** As described for Alternative 1B(12), above.

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 2B(12) includes 106 acres of removal (93 acres of removal and 13 acres of partial removal and capping), 12 acres of in situ treatment, and 3 acres of ENR-sill. The total removal volume is estimated at 900,000 cy, and the total placement volume (capping, in situ treatment, ENR, RMC layer, and backfill) is 280,000 cy. The alternative will take approximately 10 years to construct, at a cost of approximately $284 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.9 Alternative 2C+(12)

Alternative 2C+(12) is based on open-water option 2 (Table 8-1): removal with capping where applicable; limited access option C+ (Table 8-2): removal followed by in situ treatment for areas with PCBs or mercury greater than the CSL and in situ treatment elsewhere; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-6.

Alternative 2C+(12) is removal focused, with removal over 90% of the remediation area (69% of the EW). Alternative 2C+(12) is the same as Alternative 2B(12), except that it includes limited removal using diver-assisted hydraulic dredging (for PCBs or mercury greater than the CSL) followed by in situ treatment as remedial technologies in underpier areas. Alternative 2C+(12) includes the following combination of remedial technologies:

- **Open-water Option 2 (Table 8-1):** As described for Alternative 2A(12), above.
- **Limited Access Option C+ (Table 8-2):** As described for Alternative 1C+(12), above.

Table 8-6 shows the total remedial areas, volumes, costs, and construction timeframes for the alternative. Alternative 2C+(12) includes 108 acres of removal (93 acres of removal, 13 acres of partial removal and capping, and 2 acres of hydraulic dredging followed by in situ treatment), 3 acres of ENR-sill, and 10 acres of in situ treatment. The total removal volume is estimated at 910,000 cy, and the total placement volume (capping, in situ treatment, ENR, RMC layer, and backfill) is 280,000 cy. The alternative has the same construction timeframe (10 years) as Alternative 2B(12), because diver-assisted hydraulic dredging would occur concurrently with open-water removal operations. Alternative 2C+(12) is estimated to cost $297 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.10 Alternative 3B(12)

Alternative 3B(12) is based on open-water option 3 (Table 8-1): maximum removal to the extent practicable in open-water areas; limited access option B (Table 8-2): in situ treatment; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-7.

Alternative 3B(12) is removal focused, with removal over 88% of the remediation area (69% of the EW). Alternative 3B(12) is identical to Alternative 2B(12), but uses removal where practicable in the open-water areas (i.e., removal in the Shallow Main Body CMAs and under the West Seattle Bridge). Alternative 3B(12) includes the following combination of remedial technologies:

- **Open-water Option 3 (Table 8-1):**
  - **Navigation Channel and Berth Area:** Removal. The Communication Cable Crossing includes removal to the extent practicable and backfill instead of removal to RAL exceedances to protect the structure (same as described for Alternative 2B(12)).

- **Shallow Main Body Reach:** Removal.
- **Nearshore:** Partial removal and cap (same as described for Alternative 1A(12)).
- **West Seattle Bridge:** Removal.

- **Limited Access Option B (Table 8-2):** As described for Alternative 1B(12), above.

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 3B(12) includes 108 acres of removal (101 acres of removal, 7 acres of partial removal and capping), 12 acres of in situ treatment, and 1 acre of ENR-sill. The total removal volume is estimated at 960,000 cy, and the total placement volume (capping, in situ treatment, ENR, RMC layer, and backfill) is 270,000 cy. The alternative will take approximately 10 years to construct, at a cost of approximately $298 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.11 Alternative 3C+(12)

Alternative 3C+(12) is based on open-water option 3 (Table 8-1): maximum removal to the extent practicable in open-water areas; limited access option C+ (Table 8-2): removal followed by in situ treatment for areas with PCBs or mercury greater than the CSL and in situ treatment elsewhere exceeding RALs; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-8.

Alternative 3C+(12) is removal focused, with removal over 90% of the remediation area (70% of the EW). Alternative 3C+(12) is the same as 2C+(12) but uses removal where practicable in the open-water areas (i.e., removal in the Shallow Main Body CMAs). Alternative 3C+(12) includes the following combination of remedial technologies:

- **Open-water Option 3 (Table 8-1):** As described for Alternative 3B(12), above.
- **Limited Access Option C+ (Table 8-2):** As described for Alternative 1C+(12), above.

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 3C+(12) includes 110 acres of removal (101 acres of removal, 7 acres of partial removal and capping, 2 acres of hydraulic dredging followed by in situ treatment), 1 acre of ENR-sill, and 10 acres of in situ treatment. The total removal volume is estimated at 960,000 cy, and the total placement volume (capping, in situ treatment, ENR, RMC layer, and backfill) is 270,000 cy. The alternative will take approximately 10 years to construct, at a cost of approximately $310 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.12 Alternative 2C+(7.5)

Alternative 2C+(7.5) is based on open-water option 2 (Table 8-1): removal with capping where applicable; limited access option C+ (Table 8-2): removal followed by in situ treatment in areas with PCBs or mercury greater than the CSL and in situ treatment elsewhere above RALs; and the RAL set including 7.5 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-9.

Alternative 2C+(7.5) is removal focused, with removal over 90% of the remediation area (75% of the EW). Is identical to Alternative 2C+(12), except for a larger remediation area due to a lower RAL for PCBs. Alternative 2C+(7.5) includes the following combination of remedial technologies:

- **Open-water Option 2 (Table 8-1):** Same as described for Alternative 2B(12), above, but with a larger remediation area due to the lower RAL.
- **Limited Access Option C+ (Table 8-2):** Same as described for Alternative 1C+(12), above, but with a larger remediation area due to the lower RAL.

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 2C+(7.5) includes 118 acres of removal (103 acres of dredging, 13 acres of partial removal and capping, 2 acres of hydraulic dredging followed by in situ treatment), 3 acres of ENR-sill, and 11 acres of in situ treatment. The total removal volume is estimated at 1,010,000 cy, and the total placement volume (capping, in situ treatment, ENR, RMC layer, and backfill) is 290,000 cy. The alternative will take approximately 11 years to construct, at a cost of approximately $326 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.13 Alternative 3E(7.5)

Alternative 3E(7.5) is based on open-water option 3 (Table 8-1): maximum removal to extent practicable; limited access option E (Table 8-2): removal followed by in situ treatment in all areas exceeding RALs; and the RAL set including 7.5 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-10.

Alternative 3E(7.5) can be considered the overall most aggressive removal-focused alternative with maximum removal in the open-water areas due to a PCB RAL of 7.5 mg/kg OC, combined with hydraulic dredging followed by in situ treatment in underpier areas. Alternative 3E(7.5) includes the following combination of remedial technologies:

- **Open-water Option 3 (Table 8-1):** Same as described for Alternative 3C+(12), above, but with a larger remediation area due to the lower RAL.
- **Limited Access Option E (Table 8-2):**
  - **Underpier areas:** Removal using hydraulic dredging followed by in situ treatment.
  - **Sill Reach – Low Bridges:** ENR-sill (same as Alternative 1B(12)).

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 3E(7.5) includes 131 acres of removal (111 acres of removal, 7 acres of partial removal and capping and 13 acres of hydraulic dredging followed by in situ treatment) and 1 acre of ENR-sill, The total removal volume is estimated at 1,080,000 cy, and the total placement volume (capping, ENR, RMC layer, and backfill) is 270,000 cy. The alternative will take approximately 13 years to construct, at a cost of approximately $411 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1. Additional costs and construction timeframes for this alternative are entirely due to additional underpier footprint for diver-assisted hydraulic dredging.

8.3 Uncertainties

Sufficient data collection and analyses have been completed to develop and evaluate the alternatives for the FS. Overall, the alternatives are sufficiently defined to allow a detailed evaluation against the CERCLA criteria (Section 9), to perform a comparative analysis in accordance with CERCLA criteria (Section 10), and to support remedial decision-making. However, inherent in the conceptual nature of the FS process, key uncertainties remain regarding certain assumptions made in development of the alternatives. These uncertainties are further discussed below and include, but are not limited to, the following:

- Adequacy and timing of source control
- Volume and cost estimates
- Remedial technology assignments and expected performance
- Future land and waterway uses

8.3.1 Adequacy and Timing of Source Control

Remedial actions must be carefully coordinated with source control work, and generally should not commence until appropriate source control measures have been implemented and their performance verified. In certain cases, source control may be the limiting factor in scheduling in-water cleanup. Source control programs are ongoing in and upstream of the EW.

The construction timeframes and cost estimates assume that source control[92] will be sufficient prior to remediation; however, the timing and costs of remediation will be modified as more information is collected and integrated into remediation of the site.

8.3.2 Volume and Cost Estimates

Remedial design sampling will refine the estimated extent of contaminated sediment and confirm or modify the technology assignments identified in the FS. The assumptions used to define the remedial areas and volumes set forth in this section are reasonable and appropriate for an FS-level alternatives development and comparative process.

Likewise, the cost estimate was developed using pertinent guidance and costs from recent project experience. Although these represent the best-estimate of future project costs, many factors have an impact on project costs. Some of these factors are intrinsic to the site, such as areas and volumes requiring remediation and other site conditions. Other factors are extrinsic to the site, such as general economic conditions like inflation, the cost of

[92] Cost for source control actions are not included in the remedial alternative costs.

construction, transportation, and disposal. Per FS guidance, the cost estimate is considered accurate to +50%, -30%.

8.3.3 Remedial Technologies Assignments and Expected Performance

The alternatives have been assembled using a set of assumptions about the applicability and effectiveness of remedial technologies (Section 7). Some of these are straightforward (e.g., the assumption that capping is not applicable in most areas of the Deep Main Body Reach of the navigation channel due to anticipated vertical clearance requirements for vessel operations and future maintenance dredging and the vertical extent of contamination); other criteria are based on general assumptions that require confirmation during remedial design (e.g., cap armoring necessary for a given location). In total, these assessments could result in refinements to the technologies assignments during remedial design.

The FS recognizes that new technologies should not be discounted for consideration in the cleanup of the EW OU. For example, advances in in situ treatment and capping amendments may have the potential to improve cleanup and should be considered at the remedial design stage.

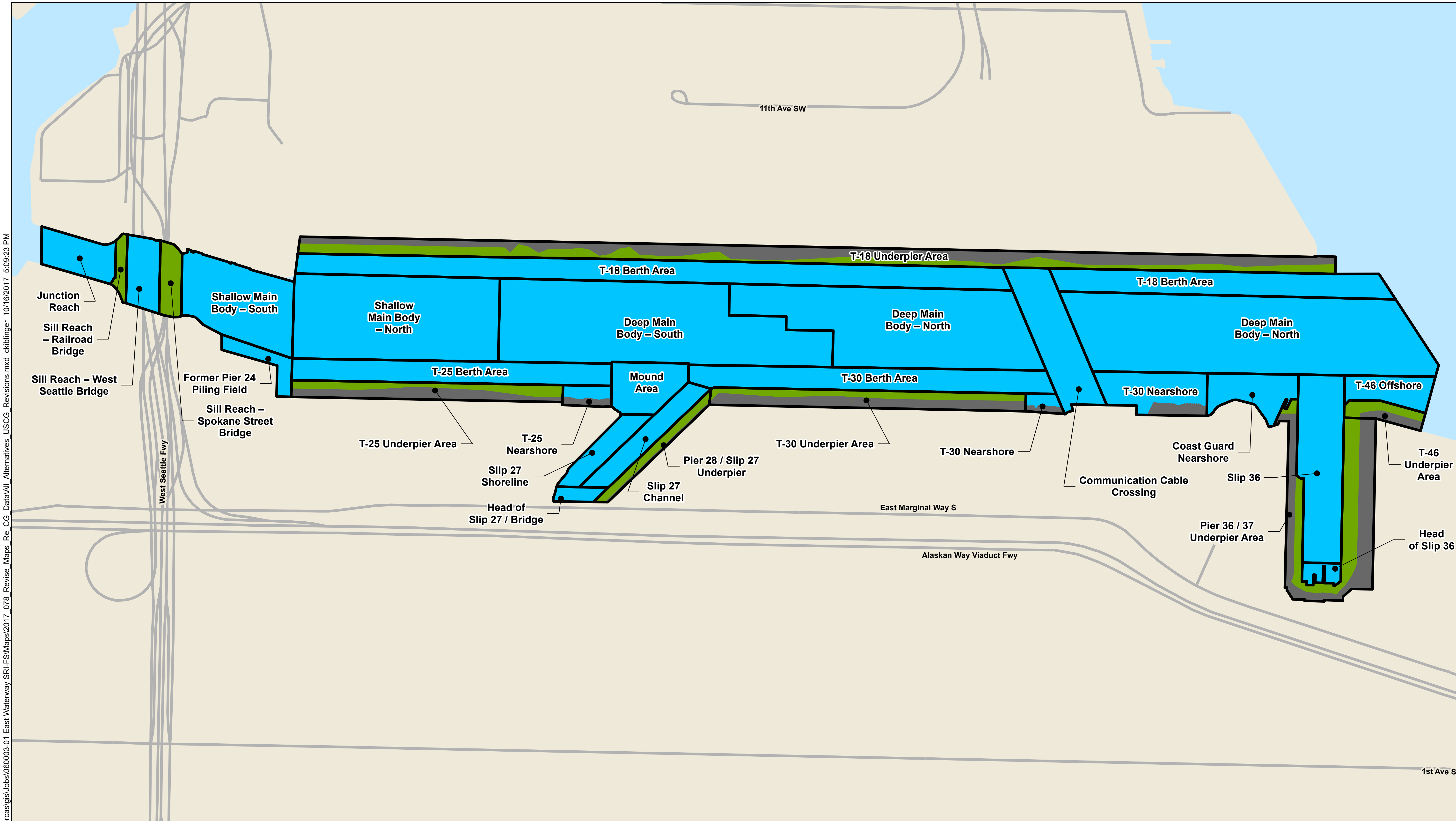
8.3.4 Future Land and Waterway Uses

The EW OU is an active port area and is intended to remain so. The waterway is expected to continue to be used by Muckleshoot and Suquamish Tribes for fishing and harvesting activities. Land bordering it is zoned for industrial and manufacturing uses. Two local jurisdictions have regulatory authority in the area near the EW: the City of Seattle and King County. These jurisdictions, along with the Port, have established planning priorities and goals for the EW that are described in the following planning documents:

- City of Seattle Comprehensive Plan 2012, available from: http://www.seattle.gov/DPD/Planning/Seattle_s_Comprehensive_Plan/Overview/
- City of Seattle Shoreline Master Program Updates 2012, available from: http://www.seattle.gov/dpd/Planning/ShorelineMasterProgramUpdate/Overview/
- King County Comprehensive Plan 2012, available from: http://www.kingcounty.gov/depts/executive/performance-strategy-budget/regional-planning/king-county-comprehensive-plan/2012Adopted.aspx

- King County Shoreline Master Program Update 2010, available from: http://www.kingcounty.gov/environment/waterandland/shorelines/program-update.aspx

As discussed in Section 2.9.2, USACE completed a draft SHNIP Feasibility Report and Environmental Assessment in August 2016 (USACE 2016) evaluating several alternatives for deepening and widening the federal navigation channel in the EW. No decision has been made to proceed with the recommended navigation improvement project, as implementation depends on approval and funding by the federal government and other parties. Therefore, the FS remedial alternatives are based on the current conditions and uses of the waterway. However, all of the EW remedial alternatives are compatible with the future implementation of the potential navigation improvement project, and the navigation improvement would not reduce the environmental protectiveness of the remedy in the EW.



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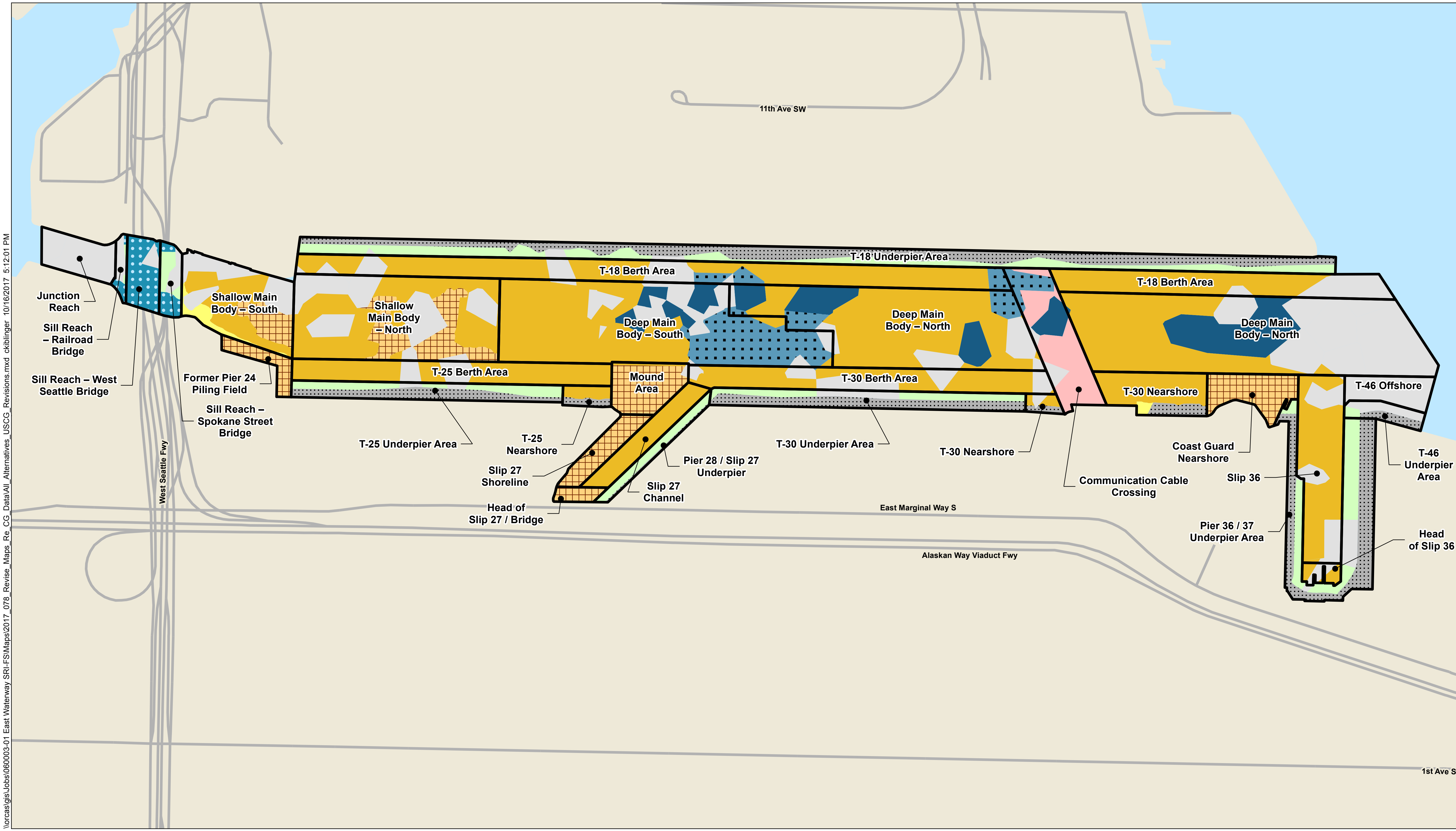
CMA Boundaries
Limited Access (Underpier and Low Bridge)
Open Water
Riprap (No Action)

0 500 1,000
Scale in Feet

Figure 8-1
Construction Management Area Groups
Feasibility Study
East Waterway Study Area



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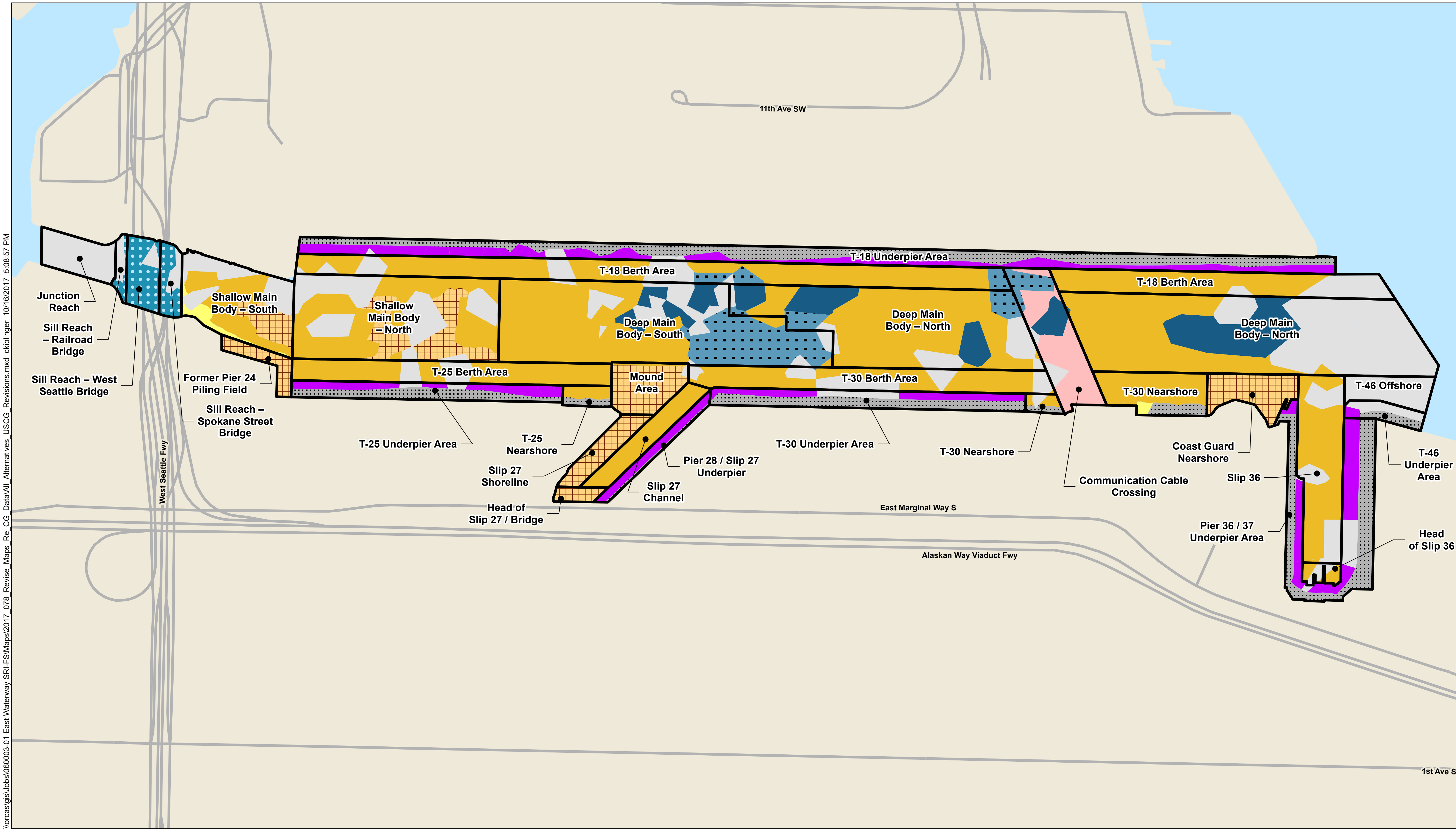
- MNR
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- Partial Removal and ENR-nav
- ENR-sill
- ENR-nav
- Riprap (No Action)
- No Action
- CMA Boundaries

0 500 1,000
Scale in Feet

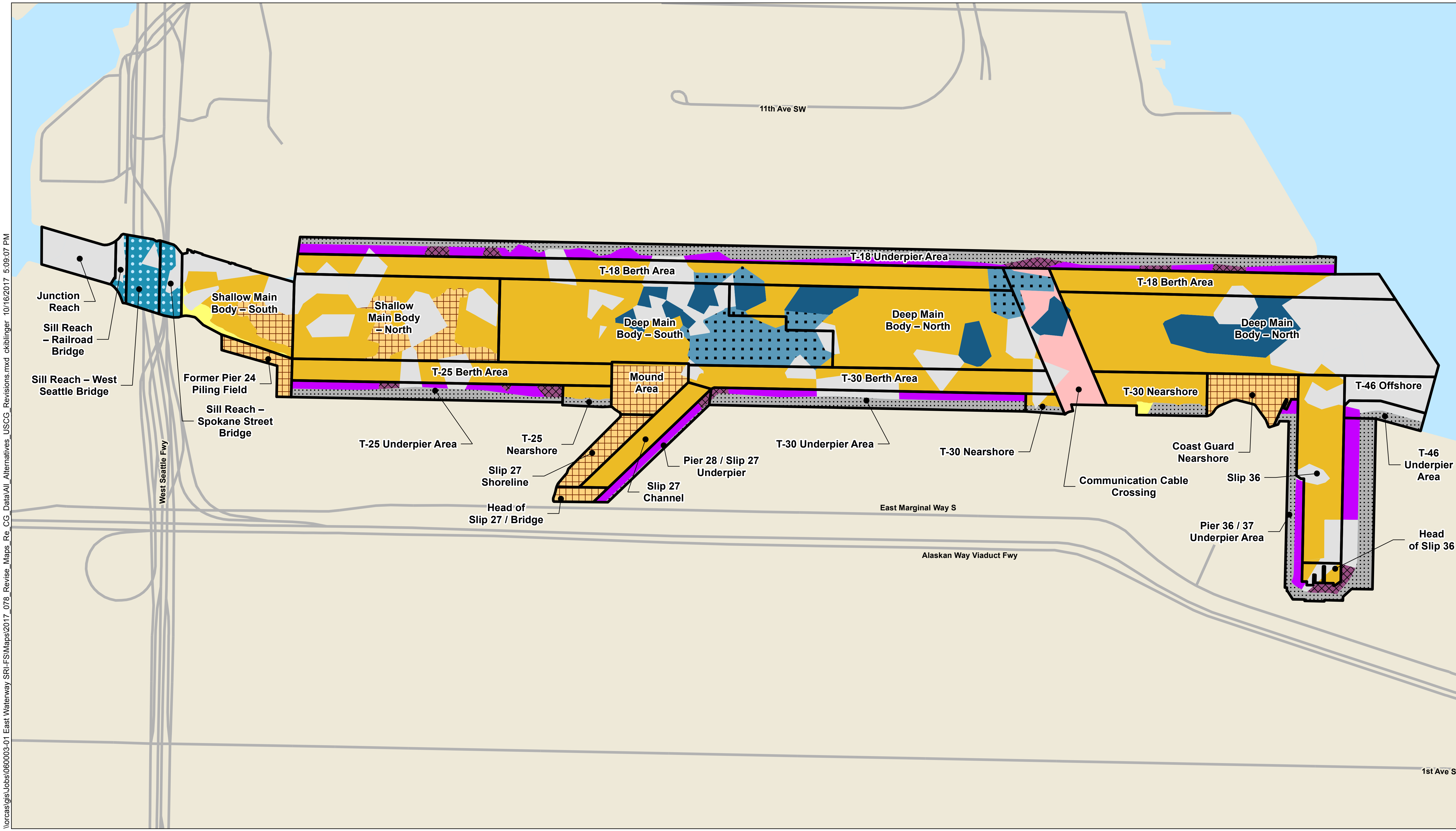
Figure 8-2
Alternative 1A(12)
Feasibility Study
East Waterway Study Area



In Situ Treatment
Removal
Removal and Backfill to Existing Contours
Removal to the Extent Practicable and Backfill
Partial Removal and Cap
Partial Removal and ENR-nav
ENR-sill
ENR-nav
Riprap (No Action)
No Action
CMA Boundaries

0 500 1,000
Scale in Feet

Figure 8-3
Alternative 1B(12)
Feasibility Study
East Waterway Study Area



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- Hydraulic Dredging Followed by In Situ Treatment
- In Situ Treatment
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- Partial Removal and ENR-nav
- ENR-sill
- ENR-nav
- Riprap (No Action)
- No Action
- CMA Boundaries

0 500 1,000

Scale in Feet

Figure 8-4

Alternative 1C+(12)

Feasibility Study

East Waterway Study Area

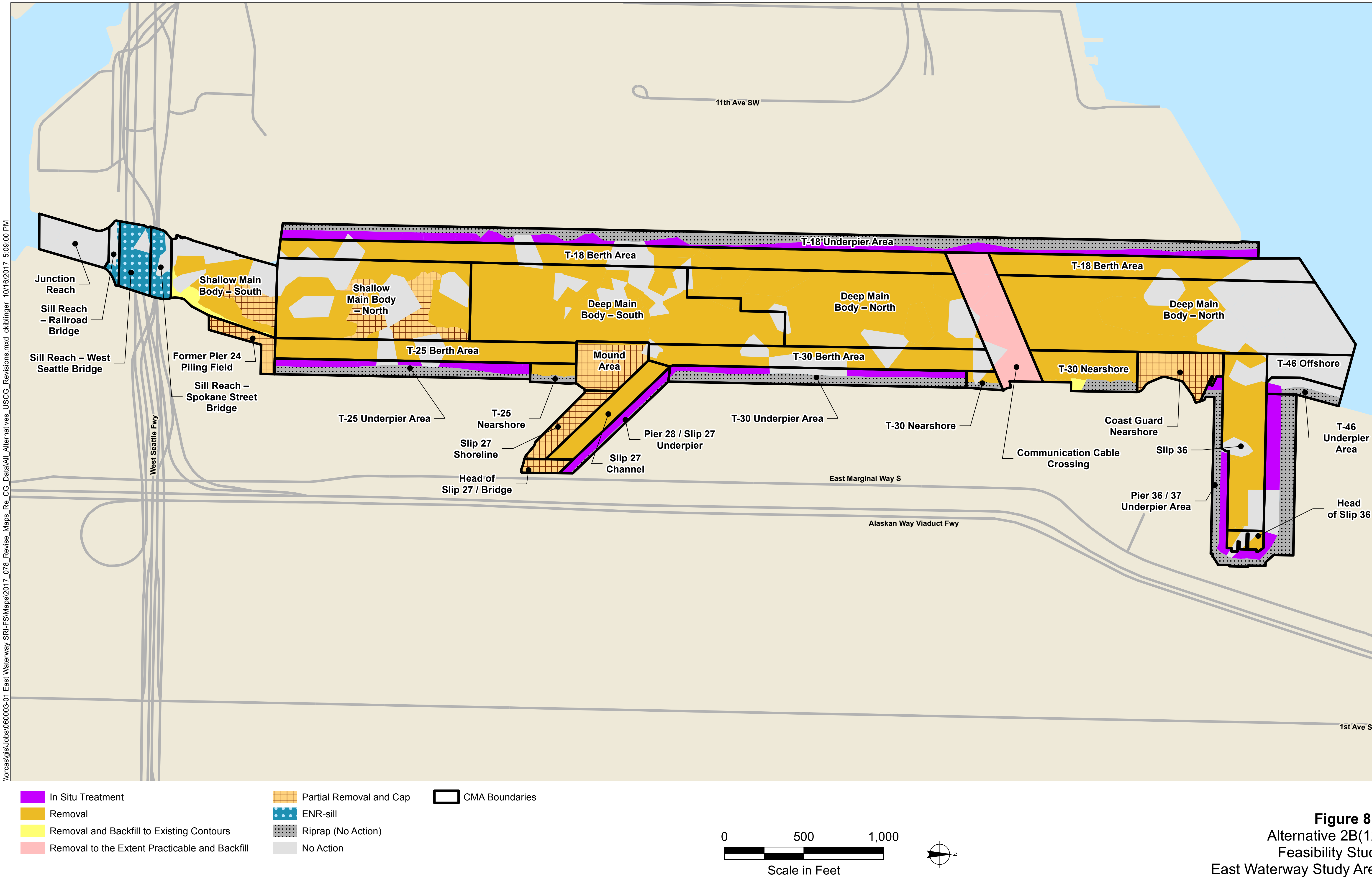
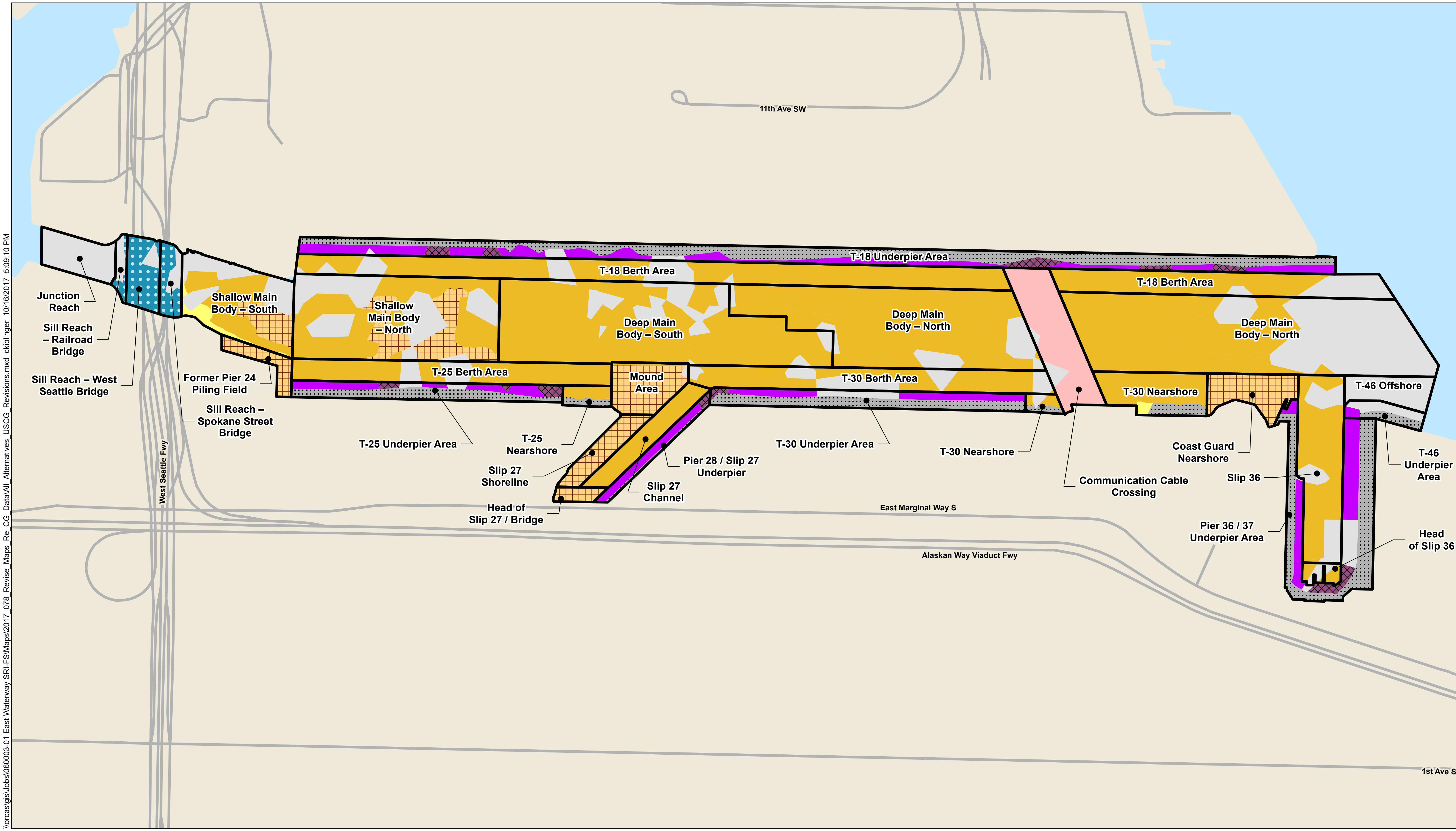


Figure 8-5
Alternative 2B(12)
Feasibility Study
East Waterway Study Area



Hydraulic Dredging Followed by In Situ Treatment
In Situ Treatment
Removal
Removal and Backfill to Existing Contours
Removal to the Extent Practicable and Backfill
Partial Removal and Cap
ENR-sill
Riprap (No Action)
No Action
CMA Boundaries

0 500 1,000
Scale in Feet

Figure 8-6
Alternative 2C+(12)
Feasibility Study
East Waterway Study Area

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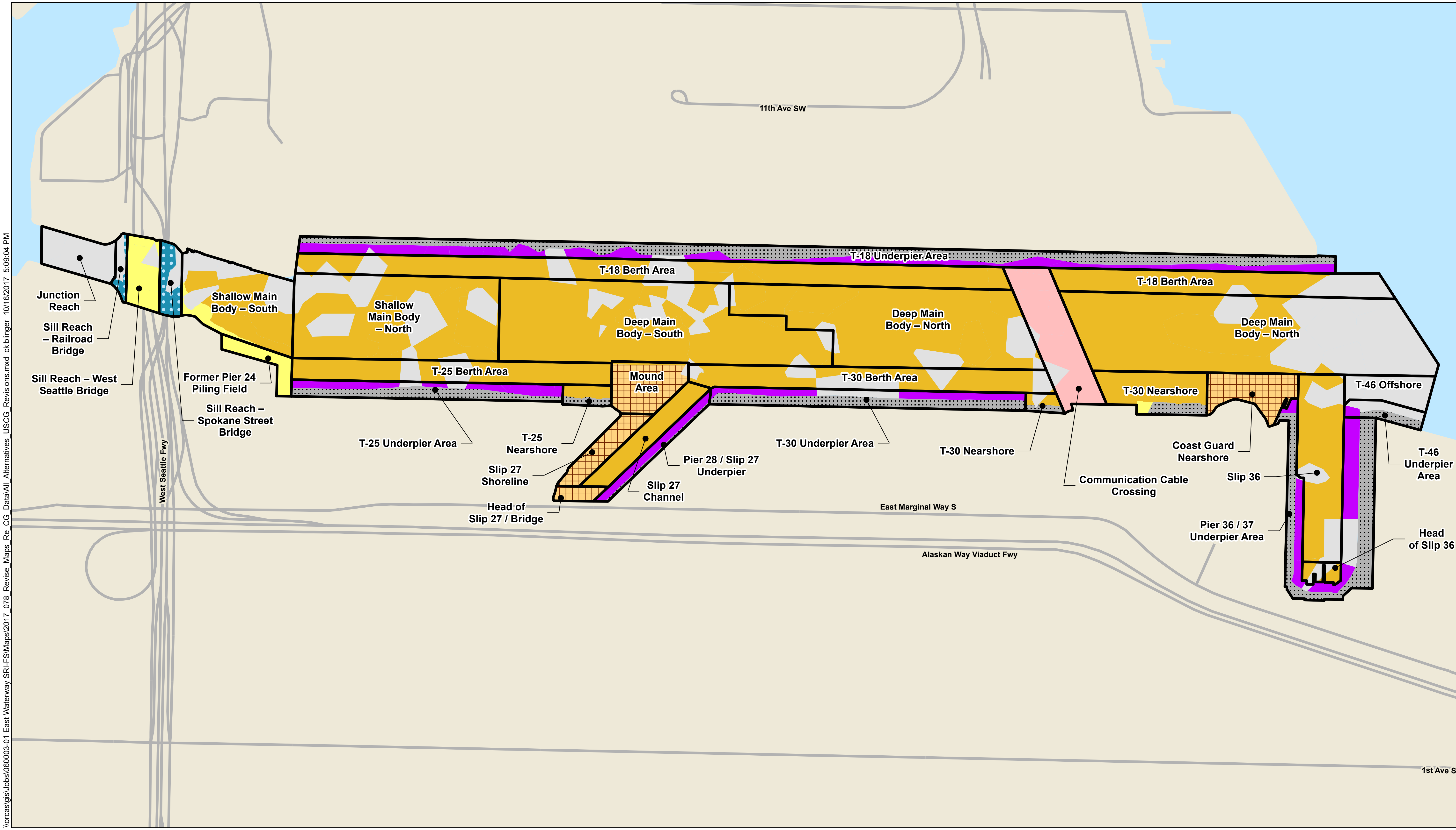

ENR-sill
In Situ Treatment
Removal
Removal and Backfill to Existing Contours
Removal to the Extent Practicable and Backfill
Partial Removal and Cap
Riprap (No Action)
No Action
CMA Boundaries

0 500 1,000
Scale in Feet

Figure 8-7
Alternative 3B(12)
Feasibility Study
East Waterway Study Area

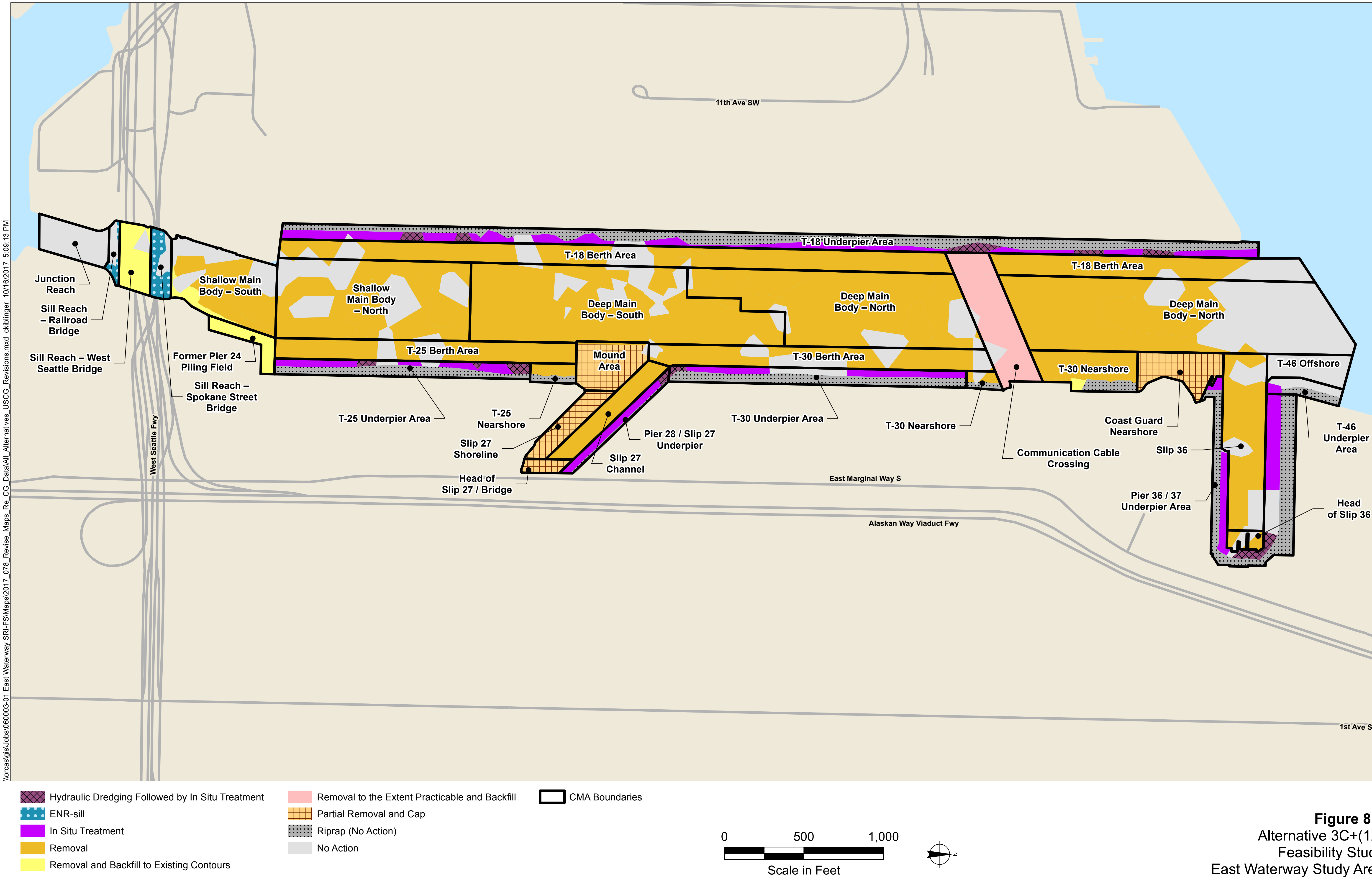

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Figure 8-8
Alternative 3C+(12)
Feasibility Study
East Waterway Study Area

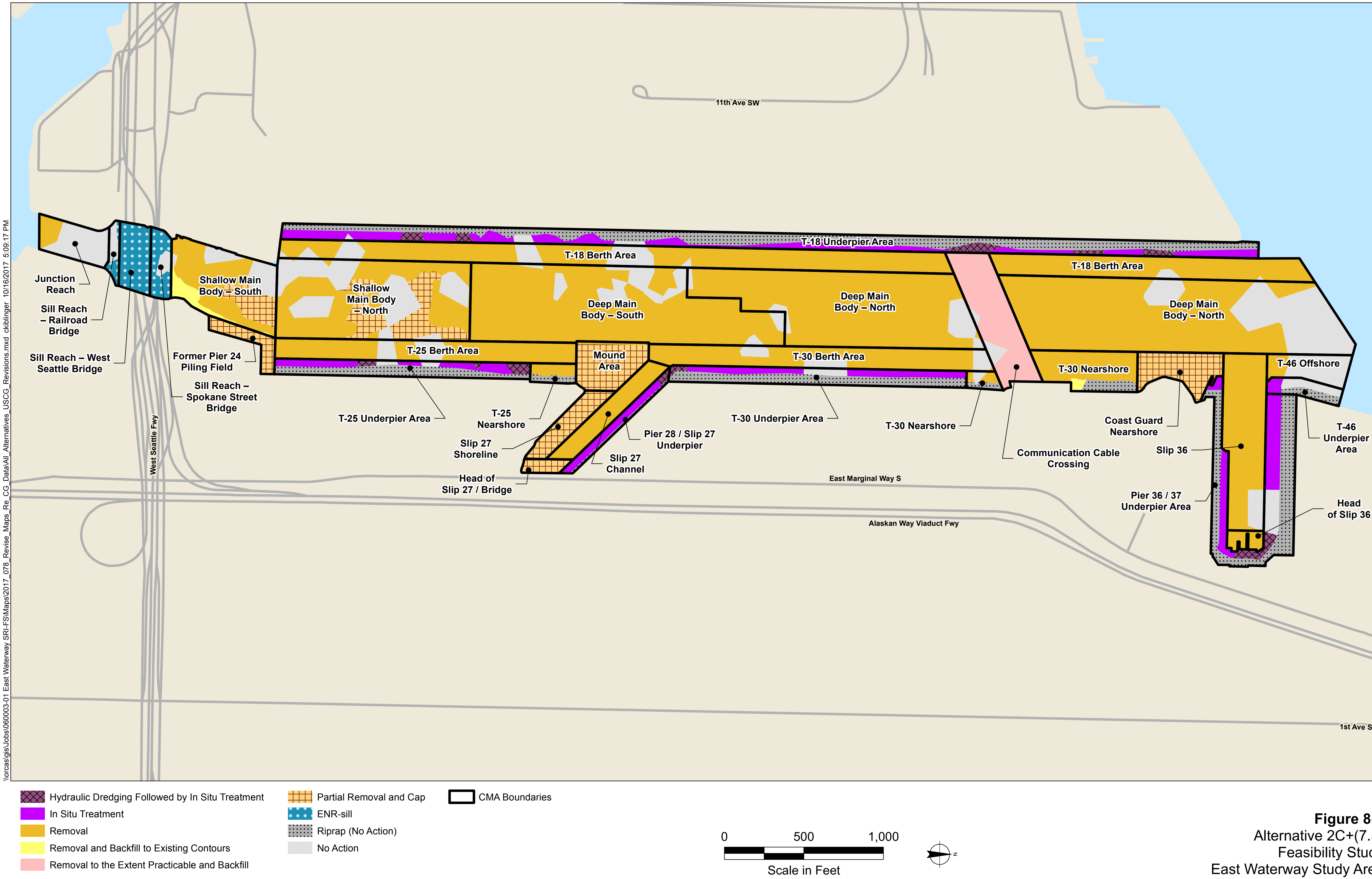

Figure 8-9
Alternative 2C+(7.5)
Feasibility Study
East Waterway Study Area

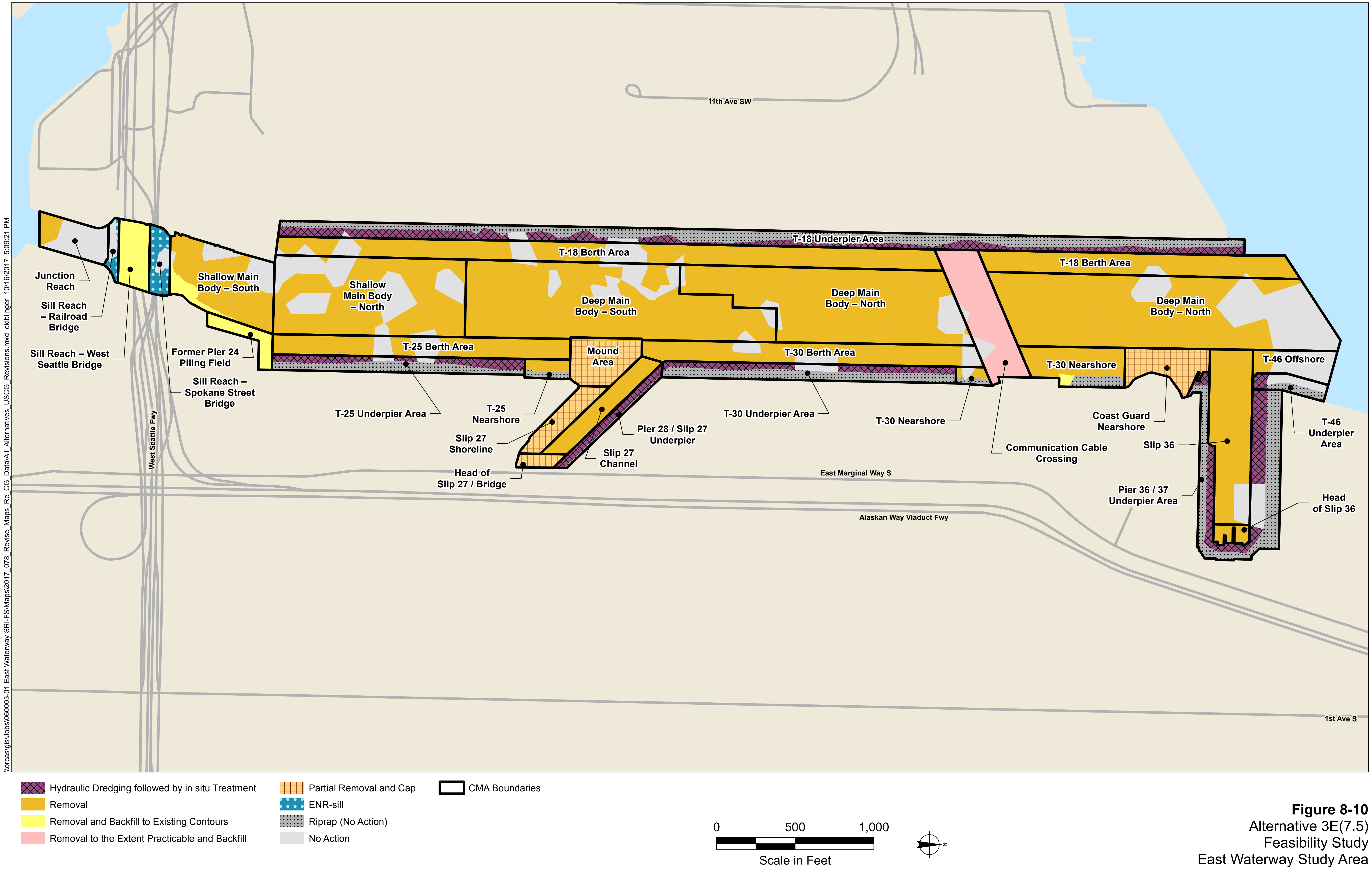

Figure 8-10
Alternative 3E(7.5)
Feasibility Study
East Waterway Study Area

9 DETAILED ANALYSIS OF ALTERNATIVES

This section presents a detailed analysis of the alternatives, using the FS criteria outlined in CERCLA and the NCP. As discussed in Section 8, these alternatives cover a representative range of potential remedial actions designed to satisfy the remedial action objectives for cleanup of the EW OU. A comparative evaluation of the alternatives under CERCLA occurs in Section 10.

9.1 Overview of National Contingency Plan Evaluation Criteria

The NCP requires consideration of nine evaluation criteria to address the CERCLA statutory requirements. The first two criteria are categorized as threshold criteria and must be met to be considered viable as a remedy for cleanup in the EW OU:

- Overall protection of human health and the environment
- Compliance with ARARs

The next five criteria are balancing criteria, which are weighed within the context of evaluating an alternative as a whole:

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost

These seven threshold and balancing criteria listed above form the basis for the detailed evaluation in this FS.

The last two criteria are modifying criteria, which are typically assessed following agency and public comment on EPA's Proposed Plan:

- State/tribal acceptance
- Community acceptance

The CERCLA criteria are used to evaluate each alternative. The key ideas and concepts embodied by the criteria and application to the specific circumstances of the EW are presented in the following subsections.

9.1.1 Threshold Criteria

CERCLA prescribes threshold criteria that must be met by an alternative. This section discusses how an alternative achieves these criteria, serves as a summary of how the EW alternatives meet the RAOs, and discusses what expected statutory or other relevant requirements must be achieved during implementation of the remedial action.

9.1.1.1 Overall Protection of Human Health and the Environment

This criterion addresses whether an alternative provides adequate protection of human health and the environment. EPA guidance (EPA 1988) states that the assessment of overall protection draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and short-term effectiveness. The assessment of overall protection provided for each alternative describes how site risks are eliminated, reduced, or controlled using treatment, engineering controls, institutional controls, or, more typically, a combination of these general response actions.

9.1.1.2 Compliance with ARARs

ARARs for cleanup of the EW OU were presented in Section 4.1. Two ARARs to evaluate the alternatives are discussed in this section: federal and state surface WQS (RCW 90-48 and WAC 173-201A, respectively) and MTCA including the Washington SMS (WAC 173-204), which apply to sediment cleanup sites. National recommended federal WQC developed to protect ecological receptors and human consumers of fish and shellfish are relevant and appropriate requirements pursuant to CERCLA Section 121 (d)(2)(A)(ii) and RCW 70.105D.030(2)(e).[93] More stringent state surface WQS apply where the state has adopted, and EPA has approved, WQS that are more stringent than the federal recommended WQC

[93] However, federal recommended ambient water quality criteria for consumption of organisms and water are not relevant because the EW is not a source of drinking water.

established under Section 304(a) of the CWA.[94] Both chronic and acute standards for marine water are used as appropriate.

The SMS are used to establish cleanup levels for sediment under MTCA and contain numerical criteria (SQS[95] and CSL) for the protection of biological resources, including benthic invertebrate organisms. The SMS also contains general methodology for developing numerical standards for the protection of human health and higher trophic level species and the process for complying with and achieving SMS requirements.

The other ARARs listed in Section 4 (Table 4-1) are not discussed explicitly as part of evaluating the alternatives. The alternatives (other than the No Action Alternative) are assumed to comply with these ARARs because the required engineering design, agency review process, and the tools within SMS[96] can ensure that the selected remedy will comply with the ARARs. For example, the construction elements for the alternatives are similar in nature and scope to sediment remediation projects previously implemented in the Puget Sound region and elsewhere around the country. All of the alternatives can be designed and implemented in compliance with ARARs pertaining to management and disposal of generated materials (e.g., contaminated sediment, wastewater, and solid waste). ARARs may affect implementation of the selected remedy but do not have a marked effect on whether an alternative is fundamentally viable. Further, the remedial design phase will address the

[94] However, EPA proposed changes to the federal and state WQS in 2013, which are currently under review.

[95] The SMS list SQS as marine sediment quality standards (WAC 173-204-320). In addition, SMS has established numeric Sediment Cleanup Objective (SCO) for benthic organisms in WAC Section 173-204-562, where sediment cleanup standards are discussed. The rule also uses the term SCO to apply to standards based on protection of human health and higher trophic species (WAC Sections 173-204-561 and 173-204-564). For this reason, the term SQS has been retained for this FS and is synonymous with "SCO based on protection of the benthic community" in the SMS.

[96] Appendix A describes the SMS compliance process through which the selected alternative will meet the SMS ARAR over time either by meeting the PRGs in a reasonable restoration timeframe, or by adjusting the SCL upward once regional background levels are established for the geographic area of the EW and the attainment of those SCLs occurs in a reasonable restoration timeframe. A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

various land use and resource protection ARAR requirements (e.g., habitat preservation and mitigation).

Surface Water Quality Standards

Requirements for compliance with surface water quality ARARs during in-water construction are set in project-specific Section 401 Water Quality Certifications. These certifications generally require water quality monitoring at a compliance boundary located downstream of the construction area. Compliance with the requirements of Water Quality Certifications is expected to be met through the use of operational and structural BMPs.

Active remedial measures for the water column are not technically feasible and are therefore not included as part of the alternatives. While significant water quality improvements are anticipated from sediment remediation and source control, currently, upstream Green River and downstream Elliott Bay water concentrations are above federal recommended WQC for some chemicals, and therefore, it is not technically practicable for any alternative to meet all human health recommended federal or state ambient water quality criteria or standards that are based on human consumption of bioaccumulative contaminants (e.g., total PCBs and arsenic). EPA may determine that no additional practicable actions can be implemented under CERCLA to meet ARARs and issue a ROD Amendment or ESD providing the basis for a TI or other waiver for specified surface water quality-based ARARs under Section 121(d)(4) of CERCLA.

Model Toxics Control Act

As described in Section 4.3.1, MTCA regulations governing the selection of cleanup standards, among others, are ARARs under CERCLA. Sediment sites under MTCA are regulated by the SMS, which provides risk thresholds for specified exposure pathways (e.g., 1×10^{-6} excess cancer risk threshold for individual carcinogens to achieve the SCO), methods for setting the SCLs to appropriate levels up to the CSL (e.g., adjusting to regional background levels), and specific target concentrations for individual chemicals for protection of the benthic community. The PRGs were developed in Section 4.3 to be consistent with the SMS for protection of human health, the benthic community, and higher trophic level species. PRGs developed for RAOs 1 and 2 are consistent with the SMS for protection of human health, PRGs developed for RAO 3 are consistent with the SMS for protection of the benthic community, and PRGs developed for RAO 4 are consistent with the SMS for protection of higher trophic level species. The following paragraphs explain how the alternatives achieve the SMS ARAR for each RAO.

None of the action alternatives are predicted to achieve the natural background PRGs for RAO 1 for PCBs or dioxins/furans, based on modeling of the hypothetical maximum remediation scenario at the completion of cleanup implementation and modeling of long-term site-wide concentrations following source control of LDW and EW lateral inputs (see Appendix A). Long-term site-wide concentrations are driven primarily by the ongoing contribution of elevated concentrations from diffuse, nonpoint sources of contamination that contribute to regional background concentrations.

Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to meet and maintain natural background levels, regional background levels have not yet been established for the geographic area of the EW.

However, CERCLA compliance with MTCA/SMS ARARs may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations lower than current model predictions, and PRGs identified in this FS are attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Section 5 of Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition to these two potential MTCA/SMS ARARs compliance mechanisms, a final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

Because it is not known whether, or to what extent, the SMS ARARs for total PCBs and dioxins/furans will be achieved in the long term, the selection of which of the two compliance mechanisms described above (either meeting the natural background PRG in a reasonable restoration timeframe, or upwardly adjusting the SCL to regional background and meeting it in a reasonable restoration timeframe) is not identified at this time.

All alternatives (except for No Action) are predicted to meet the natural background-based RAO 2 PRG for arsenic of 7 mg/kg dw (based on the UCL95; EPA 2014) immediately after construction and may maintain this value in the long term, depending on incoming sediment concentrations (Section 9.15.1.2). However, modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above 7 mg/kg dw in the long term after construction, due to incoming sediment concentrations, meaning that the RAO 2 PRG for arsenic is predicted to be met only temporarily

The achievement of RAO 3 in this FS is estimated for key benthic risk driver COCs (total PCBs, arsenic, mercury, total HPAHs, total LPAHs, BEHP, and 1,4-dichlorobenzene), which serve as surrogate for the 29 SMS contaminants identified as benthic invertebrate community COCs in the ERA. The PRGs (the SQS or benthic SCO, based on SMS numerical criteria) are applied to these COCs on a point-by-point basis. For the purposes of the FS, an alternative's ability to achieve RAO 3 is approximated by at least 98% of existing surface (where potentially exposed from propwash) sediment sample locations with key benthic risk driver COC concentrations predicted to be below the PRGs. This metric acknowledges that the SMS has some flexibility in defining practicability for compliance with the SQS. In addition, the FS recognizes that, given the uncertainty in predictions of future contaminant concentrations based on model- and contaminant-specific assumptions, achievement of 100% compliance with the SQS may not prove to be practicable. Small numbers of SQS point exceedances may represent the potential for isolated minor adverse effects on the benthic community, and those do not necessarily merit further action based on a number of factors (such as sediment toxicity test results), as prescribed in the SMS. Adaptive management measures (e.g., verification monitoring, contingency actions) may become necessary, consistent with the technical feasibility provisions of the SMS, in response to isolated or localized SQS point exceedances. This metric is used for FS area and cost estimating purposes only and will not be used for determining post-cleanup compliance with the SMS.

All alternatives are predicted to achieve the RAO 4 PRGs.

9.1.2 Balancing Criteria

The following subsections describe the CERCLA balancing criteria and the metrics used to evaluate each criterion.

9.1.2.1 Long-term Effectiveness and Permanence

This balancing criterion evaluates the relative magnitude and type of residual risks that would remain at the site after remediation under each alternative. In addition, this criterion assesses the adequacy and reliability of the controls that are used to manage residual risks from contamination remaining at the site after remediation.

Magnitude and Type of Residual Risk

CERCLA RI/FS guidance refers to residual risk "…from untreated waste or treatment residuals at the conclusion of remedial activities," stating that the "…potential for this risk may be measured by the volume or concentration of contaminants in waste, media, or treatment residuals remaining on the site." Evaluation of this form of residual risk following remediation of the EW OU focuses on the potential for exposure of sediments that contain COCs above RALs. Each alternative considered two types of residual risk following cleanup.

The first type is the residual risks to humans, fish, and wildlife, and the benthic community from surface sediment contaminant concentrations remaining on site after the completion of remediation and over time. These were estimated for human health, fish and wildlife by using predicted site-wide SWACs over time derived from box model output, as described in Section 9.2.1. For the benthic community, a point mixing model was used to evaluate residual risk based on location-specific data, as discussed in Section 9.2.2. The second type of residual risk, which is the focus of the remainder of this subsection, is the risk from contaminated subsurface sediment that is left in place after remediation (e.g., under caps or in areas remediated by ENR-sill, partial removal and ENR-nav/ENR-nav, in situ treatment, or MNR), which might be transported to the surface through disturbance.

The magnitude and type of residual risk is evaluated in this FS with the following factors: potential disturbance of subsurface sediment and contamination remaining in subsurface after remediation.

Mechanisms for deep disturbance of subsurface sediment include vessels maneuvering under typical and extreme operations, ship groundings, operations such as pier construction/maintenance activities, or other types of scour, as described below:

- Construction is a main disturbance factor of subsurface sediment, but it is also a regulated activity that is expected to be managed through institutional controls.
- Natural erosion or scour from high-flow conditions in the EW was evaluated as part of the STE (Anchor QEA and Coast & Harbor Engineering 2012). As discussed in Section 5.1.4, it is anticipated that significant bed scour or erosion of in situ bed sediments within the EW are not predicted to occur as a result of tidal or riverine currents. The maximum predicted scour depths within the EW from vessel operations (including impacts from propwash and pressure fields) are presented in Section 5.1.5; surface sediments within the waterway have the potential to be eroded due to vessel operations throughout the majority of the EW, with predicted scour depths ranging from 0.3 to 4.7 feet.[97] Maneuvering of vessels used for construction may be managed through BMPs.
- Other types of scour that may occur in the EW (that were not modeled in the FS) include earthquake-induced movements of sediment and scour from flows larger than the Howard Hanson Dam's ability to regulate.[98] Earthquakes are mechanisms with the potential to expose subsurface contamination in both magnitude and duration sufficient to increase average surface sediment contaminant concentrations. As

[97] Based on both typical and extreme vessel operations.

[98] The Howard Hanson Dam is designed to manage flows at a 144-year return flood.

discussed in Section 2.14.5, earthquakes could expose subsurface contamination either directly as a result of the ground motion or indirectly (e.g., tsunamis). Earthquake effects are difficult to predict because the nature and magnitude of ground motions depend on earthquake type, location of the epicenter, and magnitude. Also, exposure of subsurface contamination is not the only means whereby surface sediment concentrations and associated risks can increase following an earthquake. Upland impacts caused by earthquakes, both laterally and upstream (e.g., spills, liquefaction of upland soils and sediment beds, landslides, slope failures), could affect post-earthquake surface sediment conditions.

The potential and magnitude of subsurface contaminant exposure from these disturbance mechanisms decreases as the concentration and area of subsurface contamination decrease and the depth to contamination increases. Two metrics were used in this FS to semi-quantitatively assess the magnitude of remaining subsurface contamination for each alternative, which focused on areas where exposure of subsurface sediment has the greatest potential to increase surface sediment concentrations. The metrics used included:

- **The number of sediment cores in the EW FS dataset that have COC concentrations above the RAL (or SQS) or CSL at any depth.** For each alternative, core counts with remaining contamination were reported separately for each of the technologies (partial removal and cap, in situ treatment, partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR) in order to discuss how the disturbance potential varies by technology. The FS dataset contains 146 cores locations with the majority of the data collected for the purpose of site-wide characterization, and therefore, the dataset is well distributed spatially and representative of the site as a whole. The number of cores remaining with RAL (or SQS[99]) or CSL exceedances in these locations is one indicator of subsurface contamination that would remain after implementation of each alternative and evaluates the post-construction potential to increase surface sediment concentrations in the event of exposure of subsurface contamination. The greatest exposure potential is from areas outside of the dredge and partial dredge and

[99] This analysis was based on RALs developed for the human health risk drivers, as well as a subset of the ecological risk drivers, which include TBT and a set of indicator SMS chemicals (i.e., selected risk driver contaminants detected above the SQS in surface sediments that represent the extent of SQS exceedances).

cap areas, with partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas having smaller potential than MNR areas. Even with some contamination remaining in these areas, proposed in situ treatment, MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas represent a minor contribution (1% to 12% depending on alternatives) to the overall EW remedial footprint for all alternatives, except for Alternatives with Open-water Option 1, where these technologies account for between 24% to 26% of the overall EW remedial footprint. However, the effect of exposure of subsurface contamination due to disturbance is anticipated to be minimal for these technologies for the following reasons:

- The majority of the remedial footprint area is addressed through removal technologies.
- Predictive modeling of impacts from disturbances indicates minimal effect to overall concentrations. Sediment mixing due to vessel scour has been incorporated into predictions of surface sediment concentrations in the FS (e.g., Table 9-1a). In scour areas (e.g., the navigation channel), the upper 0.5 to 2 feet of sediment is assumed to be mixed every 5 years. In underpier areas, sediment is assumed to be mixed with a portion exchanged with open-water areas every 5 years. Therefore, the predicted surface sediment concentrations account for the effect of vessel scour by assuming that subsurface sediment, surface sediment, and placed material (e.g., ENR material) are periodically mixed.
- Specification of aggregate mixes for ENR material can be designed and implemented to reduce impacts from the types of scour associated with typical and extreme vessel operations.
- Monitoring and adaptive management of these areas would trigger contingency actions if subsurface contamination is exposed.

• **Areas (acres) that are not removed and that, as a consequence, leave some degree of contamination in the subsurface.** Surface areas remediated by the various technologies serve as another relative indicator of the potential for exposing subsurface contamination because remedial technologies other than removal leave subsurface contamination in place. This metric does not imply that unacceptable subsurface contaminant concentrations necessarily exist across the full extent of areas where there is no removal. Nevertheless, more dredged areas within the EW represent less subsurface contamination that could potentially be exposed.

Although this analysis considered that exposure potential is equally important for capped, partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas, caps are engineered systems with a higher degree of protectiveness, intended to ensure isolation and designed to handle location-specific conditions up to predetermined design thresholds.[100] The potential for subsurface sediment to be exposed by scour from propwash disturbances is greater beneath MNR, ENR-sill, partial removal and ENR-nav/ENR-nav, and in situ treatment areas, and depending on location, the appropriate technology is employed. However, proposed MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas represent a minor contribution (1% to 2% depending on alternatives) to the overall EW remedial footprint, except for Alternatives with Open-water Option 1 (where these technologies account for between 16% to 26% of the overall EW remedial footprint). All open-water areas, excluding areas with caps, are anticipated to have sediments vertically mixed as a result of propwash disturbances, and such mixing, dependent on vessel operation areas, has been incorporated into the long-term modeling. The potential for subsurface sediment to be exposed by propwash disturbances diminishes in severity and duration as natural recovery and further burial progress.

Appendix H describes the location-specific evaluations of the alternatives considered technology assignments, the extent of subsurface contamination removed, and the COCs responsible for subsurface sediment contamination remaining (defined for this analysis as detected contaminant concentrations exceeding the RAL). This valuable information can be used to evaluate the alternatives, review the dredging volume estimates, and plan location-specific remedial design investigations to refine the extent of subsurface contamination, and

[100] Based on preliminary cap modeling in Appendix D, a 5-foot-thick cap has been assumed, representing 1.5 feet of armor to protect from vessel scour, 1 foot of filter material, and 2.5 feet of isolation material, with an expected design life of more than 100 years. Thinner caps incorporating carbon/other treatment media may also be feasible. This will be evaluated during remedial design, along with seismic considerations. Contingency remedial actions include provisions for monitoring and adaptive management activities following an extreme disruptive event such as an earthquake/tsunami to assess potential impacts and to develop appropriate response actions to address any identified release.

the technology assignments during remedial design. Appendix H contains plan-view maps of the alternatives that provide a spatial distribution of remaining subsurface contamination and show the technology assignments and the subsurface contamination remaining at any depth with the SMS exceedance status for each core location following remediation. A summary of Appendix H with post-construction subsurface conditions (i.e., remaining subsurface contamination) is presented for each alternative under the long-term effectiveness and permanence criterion subsection (see Table 9-10).

These metrics are used to predict the area of remaining subsurface contamination following construction of each alternative and the magnitude of that remaining contamination.

Adequacy and Reliability of Controls

This factor assesses the adequacy and reliability of controls used to manage contaminated sediment that remains at the site. For the EW, this includes the following monitoring components:

- No Action Alternative – No Action assumes only a site-wide long-term monitoring program (to track the existing natural recovery processes).
- For the action alternatives, the amount of monitoring and maintenance is evaluated based on the areas undergoing remediation by capping, ENR-sill, partial removal and ENR-nav/ENR-nav, in situ treatment, and MNR. Areas that are dredged yield long-term or permanent risk reduction by removing contamination from the EW, but can result in short-term water quality impacts from dredging releases, such as the increased fish and shellfish tissue concentrations, the disturbance of the benthic community, and may potentially have longer term impacts from dredge residuals. Dredged areas will require management of post-removal residuals, either by placement of backfill/sand cover or natural recovery, but may require the least amount of long-term monitoring and maintenance. Areas that are capped yield more permanent risk reduction than those addressed by ENR-sill or partial removal and ENR-nav/ENR-nav, in situ treatment, or MNR and require moderate amounts of long-term monitoring and maintenance to ensure that subsurface contamination remains in place. MNR, ENR-sill, partial removal and ENR-nav/ENR-nav, and in situ treatment require a longer period of higher level of monitoring to track surface

sediment conditions over time until results indicate that contaminant concentrations have reached or are maintained at acceptable levels. In all cases, physical and chemical monitoring data will be used to determine the condition of the remedy as part of adaptive management. Repairs, such as thin-layer sand applications, could be needed or, if necessary, could involve engineered cap repairs or removal of contaminated sediment.

- EW-wide institutional controls are a required element of the action alternatives to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants. As discussed in Section 7.2.2, an ICIAP for the EW would include a notification, monitoring, and reporting program for areas of the EW where contamination remains in place to ensure the performance of the remedy. This program may include elements such as proprietary controls and designation of RNAs to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. In addition, the ICIAP will include seafood consumption advisories and public outreach and education programs because none of the alternatives are predicted to achieve risk threshold concentrations that are below background concentrations.

For FS evaluation purposes, the adequacy and reliability of the controls (monitoring, maintenance, and institutional controls) are discussed based on the area remediated by capping, ENR-sill, partial removal and ENR-nav/ENR-nav, in situ treatment, and MNR.

9.1.2.2 Reduction of Toxicity, Mobility, or Volume through Treatment

This criterion assesses the degree to which site media are treated to reduce the toxicity, mobility, or volume of contaminants permanently and significantly. This assessment is accomplished by analyzing the destruction of toxic contaminants, the reduction of the total mass of toxic contaminants, the irreversible reduction in contaminant mobility, or the reduction in total volume of contaminated material that is accomplished by one or more treatment components of the alternative.

The NCP (40 CFR Section 300.430(a)(1)(iii)) states that EPA "generally shall consider the following expectations in developing appropriate alternatives:

- …use treatment to address principal threats posed by a site, wherever practicable. Principal threats for which treatment is most likely to be appropriate include liquids, areas contaminated with high concentrations of toxic compounds, and highly mobile materials.
- …use engineering controls, such as containment, for waste that poses a relatively low long-term threat or where treatment is impracticable."

EPA guidance defines principal threat waste as a source material that is highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur, such as drummed waste or pools of non-aqueous phase liquids (EPA 1991b). No direct evidence has been found of non-aqueous phase liquids in EW sediments, and EPA has determined that contaminated sediments in the EW are low-level threat wastes (EPA 1991b).

The maximum concentrations detected for the four human health risk drivers in surface and subsurface sediment are: 184 ng TEQ/kg dw for dioxins/furans, 17,600 µg/kg dw for total PCBs, 241 mg/kg dw for arsenic, and 23,000 µg TEQ/kg dw for cPAHs (Section 2.11.2). Direct contact risks are much lower relative to seafood consumption risks (maximum site-wide direct contact RME total excess cancer risk is 5×10^{-6}, as compared to a total excess cancer risk of 1×10^{-3} for seafood consumption; see Tables 3-4a and 3-6). Based on EPA guidance, these COC concentrations classify as low-level threat waste because they are reliably contained and are near health-based levels (EPA 1991b).

This balancing criterion is designed to assess the degree to which alternatives comply with the preference for treatment in CERCLA, especially for material that qualifies as principal threat waste. Removal, capping, ENR-sill, partial removal and ENR-nav/ENR-nav, and MNR are not treatment technologies under CERCLA.[101] While these technologies reduce mobility and toxicity, they do not do so through treatment.

All alternatives (except for Alternative 1A(12)) include in situ treatment using activated carbon or other sequestering agents as a remedial technology in underpier areas. Activated carbon lowers the mobility of contaminants, reducing the toxicity and bioavailability to biological receptors directly in areas where it is applied and indirectly site-wide through reduced releases to the water column, which lowers average exposure to receptors. For this reason, alternatives with more area remediated by in situ treatment rank comparatively higher for this balancing criteria than alternatives relying on any non-treatment technologies.

9.1.2.3 Short-term Effectiveness

Short-term effectiveness addresses how an alternative affects human health and the environment during the construction phase of the remedial action and until RAOs are achieved. This criterion includes the protection of workers and the community during construction, environmental impacts that result from construction and implementation, and the length of time until RAOs are achieved.

Community and Worker Protection

Short-term impacts to human health are evaluated based on the following metrics:

- Local transportation impacts (traffic, noise, and air pollution) resulting from the implementation of the alternatives may affect the community and workers. In this FS, these impacts are assumed to be proportional to the number of truck, train, and barge miles estimated for support of material hauling operations, both for the disposal of contaminated sediment and for the transportation of sand, gravel, armor stone, and activated carbon used in capping, ENR-sill, partial removal and ENR-nav/ENR-nav, backfilling of dredged areas, RMC, and in situ treatment.

[101] Some biodegradation and dechlorination of organic compounds can be expected to occur in sediments over the long term. This mechanism is considered to yield limited risk reduction for more recalcitrant contaminants compared to the primary recovery mechanism of burial.

- Work-related accidents (injuries and deaths) may occur during the construction period and are proportional to the volume of material handled, use of diver-assisted hydraulic dredging, transportation requirements, and duration and type of remedial activities. Appropriate planning and adherence to standard health and safety practices will provide some protection to both workers and the community.

In addition, general disruptions and inconveniences to the public and commercial community (e.g., noise and lights from nighttime operations, increased street and vessel traffic, and potential temporary waterway restrictions) can be expected to increase with the duration of construction.

Environmental Impacts

Short-term impacts to the environment are evaluated based on the following metrics:

- **Dredged material resuspension and releases**: Resuspension of contaminated sediment is a well-documented short-term impact during dredging,[102] based on documented experience at other sites (Bridges et al 2010; NRC 2007; City of Tacoma and Floyd Snider 2007; BBL 1995a, 1995b; Bauman and Harshbarger 1998). Coarser resuspended material resettles, primarily onto the dredged surface and areas just outside the dredge footprint (near-field). Fine-grained material that is slow to resettle may be transported well beyond the dredge operating area (far-field). Dredging also releases contaminants into the dissolved phase (i.e., the water column). Dredging-related mass transfer can be reduced by using BMPs (e.g., silt curtains, debris removal, and equipment selection; see Section 7.5.3) but cannot be eliminated. Also, release of contaminated sediment that settles back onto the dredged surface or onto areas just outside the dredge footprint (i.e., dredge residuals) are assumed to be managed through the placement of an RMC layer, similar in material and thickness as the ENR layer. As described in Section 8.1.6, the placement of the RMC sand layer is assumed to occur after all remedial activities are complete in areas where post-construction sampling and monitoring results show surface sediment concentrations are above RALs. However, short-term environmental impacts due to material resuspension may

[102] Resuspension can also occur to a lesser degree via man-made erosion events (e.g., propeller scour).

be mitigated by the placement of RMC, which would decrease the time required to achieve the RAOs.

- **Habitat and benthic community disturbance**: The degree of habitat disturbance is measured as the amount of remediation (e.g., removal, capping, ENR) in intertidal and shallow subtidal areas above -10 feet MLLW, which are critical habitat to outmigrating salmonids and important intertidal habitat. Dredging removes the existing benthic community, which must then recolonize in the biologically active zone and regain ecological functions following remediation.
- **Consumption of natural resources/energy:** The consumption of natural resources are the materials primarily in the form of quarry material (sand, gravel, and armor stone) and treatment material (activated carbon) used for in-water placement (e.g., capping, ENR-sill, partial removal and ENR-nav/ENR-nav, RMC, backfilling of dredged areas [where return to grade is assumed], and in situ treatment). The consumption of energy refers to thermal and electrical energy used during the implementation of alternatives (see Appendix I).
- **Landfill capacity utilization:** Represents the utilization of landfill space, which is proportional to the volume of dredged material removed and disposed of in the landfill, assuming a 20% bulking factor (see Appendix I).
- **Air pollutant emissions:** Estimates for air emissions based on heavy construction equipment and vehicle use and transportation are provided in Appendix I. Air pollutants include carbon dioxide (CO_2), particulate matter with a diameter below 10 and 2.5 micrometers (µm; PM_{10} and $PM_{2.5}$, respectively), carbon monoxide (CO), hydrocarbons (HCs), VOCs, nitrogen oxides (NO_x), and sulfur dioxide (SO_2).
- **Carbon footprint:** Defined as the forested area necessary to absorb the CO_2 produced during the remediation activities, based on the sequestration rate for Douglas fir trees (see Appendix I).

Time to Achieve RAOs

The time to achieve RAOs is defined as the time from when remedial construction begins to the time when PRGs are achieved.[103] The methodology applicable to each RAO used in this FS for estimating their time of achievement is listed below:

- **RAO 1 (Human Health - Seafood Consumption):** Long-term modeling results predict that none of the alternatives will achieve the RAO 1 natural background-based PRG for total PCBs and dioxins/furans. For FS purposes only, achieving 1×10^{-4} for the Adult Tribal RME, 1×10^{-5} for the Child Tribal RME, and 1×10^{-4} and 1×10^{-5} for the Adult API RME are used as risk reduction milestones for the time to achieve RAO 1 for these two risk driver COCs.
- **RAO 2 (Human Health - Direct Contact):** The time to achieve RAO 2 is the time to achieve the PRG for arsenic for the site-wide tribal netfishing and clamming direct contact RME exposure scenarios.
- **RAO 3 (Ecological Health-Benthic Organisms):** As discussed in Section 9.1.1.2, the metric used to assess the time to achieve RAO 3 is at least 98% of the existing surface (in areas exposed to propwash) sediment sample locations predicted to be below the RAO 3 PRGs for key benthic risk driver COCs.
- **RAO 4 (Ecological Health- Fish):** The time to achieve RAO 4 is the time to achieve the total PCB PRGs for English sole and brown rockfish.

The predicted outcomes are based on modeling and therefore, are subject to inherent uncertainties, primarily related to the incoming sediment concentrations associated with Green/Duwamish River and LDW inputs, the thickness and concentration of dredge residuals remaining, source control, sedimentation rate, the potential for contaminated subsurface sediments to be exposed in the future, the amount of sediment exchanged between open-water and underpier areas, and the efficacy of removal efforts (see Section 9.15 for more

[103] As described in Section 8.1.1.8, the Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15. However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15 (i.e., 100 days/season). It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15), thus, the upper end of the number of work days in a construction season could increase to around 150 days/season, decreasing the total number of years of construction by about 2 years, consistently for all action alternatives. Therefore, times to achieve RAOs could be reduced compared to those presented in Section 9.

details). Many of these factors will be further addressed during remedial design. Specific design elements and actual construction timing and sequencing may affect conditions immediately following construction, and associated long-term changes in concentrations. Uncertainty bounds on time to achieve RAOs (using the metrics described above) were not estimated, but general modeling uncertainty considerations are addressed in Section 9.15.

9.1.2.4 Implementability

This criterion assesses the technical and administrative feasibility of implementing an alternative and the availability of services and materials required for implementation. Technical feasibility encompasses the complexity and uncertainties associated with the alternative, the reliability of the technologies, the ease of undertaking additional remedial actions if necessary, and monitoring requirements.

Administrative feasibility includes the activities required for coordination with other offices and agencies (e.g., consultation, obtaining permits for any off-site activities, or rights-of-way for construction). For example, a key administrative feasibility factor for the EW is that in-water construction is not allowed year-round in order to protect juvenile salmon and bull trout migrating through the EW. The Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15 (USACE 2015); however, based on recent project experience, this FS uses the typically permitted in-water construction window from October 1 to February 15 to avoid conflicts with tribal netfishing, potential adverse effects to migrating salmon, and for consistency with the commonly accepted construction window of upstream waters (e.g., the LDW construction window is October 1 to February 15). The in-water construction window will be confirmed by EPA in consultation with the National Marine Fisheries Service and U.S. Fish and Wildlife Service before implementation. In addition, coordination is necessary with the tribes, the Port of Seattle tenants, and other waterway users to ensure that impacts to their activities are minimized during remediation.

Availability of services and materials includes the availability of necessary equipment, materials, and specialists and the ability to obtain competitive bids for construction. Dredging and capping are mature technologies. Similar remedial and non-remedial (maintenance and construction) actions have been implemented in the EW and LDW and elsewhere in the Puget Sound region. Services, equipment, and materials (e.g., sand and aggregate) are locally or regionally available. Regional upland landfills are authorized to receive contaminated sediment and have done so on several recent projects in or near the EW. Presence of piles and debris is expected to complicate, but is not likely to significantly delay construction efforts.

All of the remedial technologies employed in open-water areas are technically implementable. The technical challenges associated with dredging include the stability of structures adjacent to removal operations, and efficiently dewatering and transloading sediments. Technical challenges associated with capping include evaluating slope stability, constructing for scour mitigation, and predicting rates of contaminant transport. Technical challenges for ENR are fewer than for dredging or capping, and include predicting remedial performance accounting for physical and chemical interactions with existing sediments.

Technical challenges are greater for active remediation under piers than for open-water areas.

In situ treatment has technical challenges associated with the selection and successful placement of stable material in difficult-to-access areas with steep slopes with pile and structural stability constraints. Material would be placed with conveyors, which involve more complex operations (compared to open-water placement) but have been used successfully both regionally and nationally (see Section 8.1.2.1).

Diver-assisted hydraulic dredging has the most technical challenges of any technology applicable in underpier areas. This form of dredging is the most difficult of the underpier technologies to implement where divers will be operating the dredge on steep slopes (1.75H:1V in most areas), composed of large riprap. Dredging will be conducted in deep water, which limits dive time for each diver and may require use of decompression chambers (as required by commercial diving regulations), resulting in a large team of divers to complete the work over a period of months and years. Technical challenges are also associated with low visibility as a result of shade from the pier, water depth, and sediments suspended as part of the dredging, making the work more hazardous from a worker health and safety perspective. Debris, such as cables, large wood, and broken pilings, will also complicate the dredging and potentially generate more unsafe conditions. Technical challenges are also present with respect to the infrastructure, such as existing piling and cross bracing, which will require relocation of both floating and submerged lines into and out of each bent.

In addition, hydraulic dredging generates large quantities of slurry (sediment/water) that must be treated prior to discharge back to the waterway. Upland areas are not available for slurry storage, sediment settling, effluent treatment, testing, and discharge because of Port operations at existing terminals. Pipeline transport of the slurry to an upland staging location is also not feasible because of impacts to navigation and long pipeline transport distances in the waterway. Therefore, it is most likely that the sediment slurry will need to be handled using a portable treatment system on a barge, which limits the daily production rate and complicates the water containment, dewatering, and treatment.

Underpiers are adjacent to active berthing areas, which have averaged around 300 container ships per year and 600 total vessel calls per year in the EW. Diving schedules are likely to be significantly impacted by waterway activities, which could result in delays in completing the work. In particular, dive time may be further limited to specific diving windows, due to risks posed to divers from propwash and suction forces from transiting and berthing container vessels. Similarly, more business interruption will occur as a result of hydraulic dredging because of restricted access to areas where divers are performing underwater work. In addition, all retained diver-assisted hydraulic dredging alternatives also include the application of in situ treatment material following dredging to remediate residuals. Therefore, diver-assisted dredging also includes implementability challenges associated with underpier in situ treatment. MNR has no technical challenges in underpier areas. MNR has the lowest potential for difficulties and delays and impacts to EW tenants and users. However, MNR has the largest potential for contingency actions in the future, should the cleanup goals not be met. In addition, monitoring will be more technically challenging under piers than in open-water areas for both MNR and the active remedial technologies.

In addition to underpier remediation, all alternatives are subject to common technical implementability challenges, such as the following:

- The EW is a busy working industrial waterway, which may require locating a transloading facility elsewhere that will have to be sited and permitted.

- Careful coordination will be required among the Port, waterway users, and government agencies to design, schedule, and construct the cleanup actions.
- It will be important to evaluate whether source controls have been implemented to a sufficient degree before or as a part of remedy construction (e.g., to stabilize erodible embankments) to limit recontamination potential.

Institutional controls are a requirement of all action alternatives to manage human health risks from seafood consumption (Section 8.1.2.6). Notification, monitoring, and reporting programs (including proprietary controls and designation of RNAs) are mechanisms that will be used to protect capped, ENR-sill, partial removal and ENR-nav/ENR-nav, and MNR areas, where contamination is left in place, to ensure the performance of the remedy; therefore, they are an additional factor to consider with respect to administrative implementability of the alternatives. Other control mechanisms include seafood consumption advisories used in conjunction with public education and outreach programs. These controls are difficult to monitor and are not enforceable and are therefore generally understood to have limited effectiveness. One objective of the public education/outreach effort is to improve compliance with the advisories.

CERCLA guidance indicates that institutional controls should be relied upon only to the minimum extent practicable. These programs would likely be developed and administered by the responsible parties with EPA oversight and with participation from local governments, tribes, and other community stakeholders.

CERCLA guidance also considers the reliability of the remedial technologies as part of implementability. Dredging and capping are considered the most reliable remedial technologies because they isolate the most contamination. ENR and in situ treatment are less reliable because they rely on more complicated chemical and physical processes, such as sedimentation and contaminant adsorption. MNR is less reliable still because it relies entirely on natural processes.

Metrics used to gauge the relative magnitude of technical and administrative implementability of the alternatives include the surface areas remediated and the dredge volumes by dredge type because areas and volumes are considered proportional to the degree of difficulty to implement and manage them. Acreage subject to MNR represents only 8% of the EW area (only Alternative 1A(12) uses MNR technology) is also considered because it requires significant administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if needed.

9.1.2.5 Cost

The cost criterion evaluates the construction and non-construction costs of each alternative. Construction costs include mobilization/demobilization, other pre-construction activities (such as preparation of staging and stockpile areas and site control), removal, dewatering, offloading, disposal, material placement (engineered capping, RMC, and in situ treatment material), surveys, monitoring, sales tax, and contingency. The non-construction costs include design and permitting, project management, environmental compliance (pre-construction baseline monitoring, construction monitoring and confirmational sampling, and post-construction performance monitoring), and agency review and oversight.

Costs for contingency are included as a percentage of the construction costs (30%) to cover unknowns, unforeseen circumstances, and unanticipated conditions reducing the overall risk of cost overruns. They also include costs for contingency remedial actions to address the potential that some areas assumed in the FS to be suitable for no action or less aggressive technologies (e.g., ENR-sill, partial removal and ENR-nav/ENR-nav, or MNR) will require dredging based on information gained either during remedial design or as a result of long-term monitoring (see Appendix E).

Consistent with CERCLA guidance, the cost estimates were prepared in the absence of detailed engineering design information. The amount and quality of remedial investigation data used to develop and scope alternatives correspond to an expected accuracy for FS cost estimates of approximately -30% to +50% (EPA 2000a). Costs provided in Appendix E are intended to fall within this range of accuracy.

The cost estimates developed in this FS are net present value (NPV) and expressed in 2016 dollars.

9.1.3 Modifying Criteria

The final two detailed evaluation criteria are the modifying criteria: state and tribal acceptance and community acceptance.

EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance of the selected remedial action in the ROD following the public comment period on EPA's Proposed Plan.

9.2 Estimation of Sediment Contaminant Reduction Over Time

Performance of the alternatives with respect to long-term effectiveness, permanence, and recontamination is, in part, evaluated based on reductions in surface sediment concentrations (and therefore residual risk to humans and ecological receptors) at the completion of construction and over time. For each alternative, three predictive model evaluations were conducted: the box model, the point mixing model, and the grid model evaluations. Sections 5.3 through 5.5 present a detailed description of each of these predictive models, and Appendix J (Sections 2, 3, and 4) provides the specific inputs, mathematical calculations, and uncertainty considerations associated with each analysis. Sections 9.2.1, 9.2.2, and 9.2.3 provide a brief description of how the box, point mixing, and grid model evaluations were conducted. In addition to these evaluations for predicting sediment concentrations, general approaches for estimating tissue concentrations of total PCBs and dioxins/furans post-remedy are presented in Section 9.2.4.

9.2.1 Box Model Evaluation: Site-wide and Area-specific SWAC Output

The box model evaluation was conducted to predict the EW site-wide and area-specific SWACs over time for the four human health risk driver COCs for each alternative and were used to evaluate their performance against the PRGs for RAO 1 (total PCBs and dioxins/furans, site-wide; cPAHs in tribal clamming areas[104]), RAO 2 (arsenic site-wide and

[104] As discussed in Section 3.3.4, the clam tissue-to-sediment relationship for cPAHs in the EW based on the SRI data was too uncertain to develop a sediment RBTC, and therefore, an RAO 1 PRG for cPAHs was not developed (Windward and Anchor QEA 2014). Variables other than localized sediment concentrations are likely to be important factors in determining cPAH tissue concentrations, based on the filter-feeding behavior

in tribal clamming areas), and RAO 4 (total PCBs, site-wide). This model is based on anticipated solids deposition and sediment bed mixing (from propwash and bioturbation) in the EW and because the model output was site-wide or clamming area SWACs, it assumed that sediment deposition (from upstream and lateral sources) occurs evenly throughout the EW and that the net sedimentation rate (NSR) is constant throughout the EW (Section 5.3).

The box model evaluation calculates the site-wide SWAC by dividing the EW into sub-areas based on remedial technology and estimated mixing depth (Figures 5-4 and 5-5) so that those variations are accounted for. The site-wide and clamming SWACs were predicted as a function of time every 5 years (0 to 40 years post-remediation).

9.2.2 Point Mixing Model Evaluation: Point Output

The point mixing model evaluation was conducted to predict the EW point surface concentrations over time in MNR areas using surface and, where subject to propwash, shallow subsurface (0 to 2 feet) sediment concentrations. The analysis was conducted using seven key benthic risk driver COCs (total PCBs, arsenic, mercury, total HPAHs, total LPAHs, BEHP, and 1,4 dichlorobenzene)[105] to evaluate compliance with RAO 3 for each alternative. As discussed in Section 5.5, achievement of RAO 3 is evaluated at all (342) sample locations throughout the EW. Point mixing model predictions were conducted for 18 locations within areas planned for MNR (under piers and under bridges). All other locations are expected to meet RAO 3 PRGs following construction, either through active remediation or because they are currently below RAO 3 RALs/PRGs. These point-based concentrations were used to

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of clams, thus, any potential effect of sediment remediation on concentrations of cPAHs in clam tissue is highly uncertain. Long-term clam tissue monitoring following sediment remediation and source control may be needed to determine whether (and to what extent) decreases in cPAH concentrations in sediment result in decreases in cPAH concentrations in clam tissue. Despite these practical limits and uncertainties in remedial performance, risks can be reduced through a combination of remediation, source control, and institutional controls, with institutional controls being used only to the extent that additional remedial measures cannot practicably achieve further risk reduction.

[105] The key benthic risk drivers serve as a surrogate for all of the 29 SMS contaminants identified as benthic invertebrate community COCs in the ERA (Windward 2012a). Total PCBs and arsenic are also human health risk drivers.

evaluate the performance of alternatives against the RAO 3 PRGs by estimating the percentage of surface and shallow subsurface sediment locations predicted to be below the PRG (RALs) with respect to the total sediment locations. This model is based on anticipated solids deposition and vertical mixing assumptions (Section 5.5).

The point surface concentrations were predicted as a function of time (0 to 40 years post-remediation) in 5-year intervals, and the percentage of surface sediment locations below the RAO 3 PRGs were reported over time. The results were also compared to benthic CSL in Section 9.3.1 for context.

Predicted surface sediment point concentrations and spatial distributions of the point exceedances over time and for the key risk driver COCs are provided in Appendix J.

9.2.3 Grid Model Evaluation: Recontamination Potential

Recontamination potential evaluation following remedial actions was conducted by using a gridded model to predict spatial distributions of surface concentrations deposited from upstream and lateral inputs in the EW over time. The purpose was to determine the potential for discrete areas within the EW where deposited sediment concentrations may exceed RALs so that areas with recontamination potential are identified. This will inform future source control efforts and general areas where post-construction monitoring can be targeted. The recontamination potential evaluation was estimated throughout the EW by using the results of numerical modeling (i.e., PTM) as an input to a GIS-based grid model[106] to estimate deposited sediment concentrations post-remediation (years 1 to 40 post-remediation) in 5-year intervals for nine key risk driver COCs[107] (Section 5.4 and Appendix J).

The calculated concentrations of deposited material in each grid cell were used to determine areas within the EW with the potential to exceed RALs. These areas will be considered during design as areas that could be subject to further source evaluation and control efforts and

[106] The grid model divides the EW into contiguous square cells with a 50-foot x 50-foot resolution for use in the recontamination evaluation (Grid Model Evaluation).

[107] The nine key risk driver COCs include: total PCBs, cPAHs, dioxins/furans, arsenic, mercury, HPAHs, LPAHs, BEHP, and 1,4-dichlorobenzene.

possible post-remediation monitoring. An overall summary of recontamination potential for all the alternatives is discussed in Section 9.14, with detailed results provided in Appendix J.

9.2.4 Predicted Post-remedy Tissue Concentrations

An FWM (for total PCBs) and species-specific BSAFs (for dioxins/furans) were developed as part of the SRI (Windward and Anchor QEA 2014) to estimate relationships between concentrations in surface sediment and seafood tissue.[108] In addition to being used to calculate sediment RBTCs in Section 3.3 (also see Section 8 and Appendix C of the SRI), these tools were used to predict post-remedy tissue concentrations for these two contaminants to allow for an assessment of residual risks to support the detailed and comparative evaluation of alternatives with respect to achieving RAO 1 (Section 9.3). The subsections that follow briefly discuss the use of the FWM and species-specific BSAFs for this application.

9.2.4.1 Food Web Model

As discussed in Section 3.3.4, the EW FWM was developed in consultation with EPA (see Appendix C of the SRI [Windward and Anchor QEA 2014]) and its application for the calculation of post-remedy tissue concentrations is consistent with the approach used in the LDW FS (AECOM 2012).

For the purpose of calculating post-remedy tissue concentrations, the two key input values are the concentration of total PCBs in surface sediment (represented by the SWAC) and in surface water. The current (baseline) conditions for these parameters are as follows:

- **Surface sediment** – The surface sediment SWAC for total PCBs for the EW has been estimated to be 460 µg/kg dw.
- **Surface water** – The EW-wide mean total PCB concentration measured in water was 1.31 nanograms per liter (ng/L), and the calibrated value was 1.16 ng/L.

In the future, total PCB concentrations in sediment and water are expected to be lower following sediment remediation and source control actions within the EW.

[108] As discussed in Section 3.3.4, a tissue to sediment relationship could not be developed for cPAHs (the other seafood consumption risk driver), and thus post-remedy cPAH tissue concentrations were not calculated.

As was the case for the LDW, it is important to note that there is uncertainty associated with using the FWM to predict post-remedy tissue concentration since the model was calibrated based on existing conditions for sediment, tissue, and water.

Changes in total PCB surface sediment SWACs were predicted for each alternative over time using the box model evaluation (Sections 5.3 and 9.2.1). Predictions of total PCB concentrations in the water column were determined using best professional judgment based on ranges of total PCBs in sediment. Three different total PCB water concentrations were used, as described below. This approach is consistent with that used for the LDW FWM[109] (Windward 2010a).

- **Total PCB concentration of 0.6 ng/L in water** – This value was used in the FWM when the total PCB concentration in the surface sediment was less than 100 µg/kg dw. This water concentration was estimated by considering model output derived from King County's Environmental Fluid Dynamics Code (EFDC) model (Windward 2010a). This water concentration was used for the majority of the residual risk analyses.
- **Total PCB concentration of 0.9 ng/L in water** – This value was used in the FWM when the total PCB concentration in surface sediment was between 100 and 250 µg/kg dw. This water concentration was selected as an intermediate value between 0.6 and 1.2 ng/L.
- **Total PCB concentration of 1.2 ng/L in water** – This value was used in the FWM when the total PCB concentration in surface sediment was between 250 and 470 µg/kg dw. This water concentration was assumed to represent baseline conditions (equal to the calibrated water concentration for the EW FWM [1.16 ng/L] and slightly below the EW-wide mean concentration of 1.31 ng/L).

The porewater concentration parameter (estimated by the model) provides a mechanism for the FWM to account for the potentially higher concentrations of total PCBs at the sediment-water interface. Appendix C of the SRI provides basis and assumptions used to calibrate the EW FWM for the estimated total PCB concentrations in surface sediment and overlying water column.

[109] There are, however, differences in the flow regimes and inputs for the two waterways (e.g., the Green River is contiguous with the LDW, the EW is contiguous with Elliott Bay, and the residence time of water is longer in the LDW than in the EW). Hence, there is uncertainty in applying the assumptions about the relationship between total PCBs in water and sediment developed for the LDW to the EW.

9.2.4.2 Biota-sediment Accumulation Factor

As discussed in Section 3.3.4, site-specific dioxins/furans BSAFs for four target species (three fish and one crab) were developed as part of the SRI to calculate sediment RBTCs for the human health seafood consumption scenarios (details are presented in Section 8 and Appendix C of the SRI [Windward and Anchor QEA 2014]). As was done for the FWM and total PCBs, these BSAFs were used in this FS to calculate post-remedy tissue concentrations for the evaluation of post-remedial risks using the predicted post-remedy sediment concentrations from the box model evaluation (Section 9.2.1).

The key assumption with the use of the BSAF approach (either to calculate sediment RBTCs or post-remedy risk estimates) is that the dioxin TEQ composition patterns remain consistent in the future for sediment, both within the various tissue types and across species. It is unknown whether these relationships will change in the future, and thus there is uncertainty in the application of these BSAFs for predicting post-remedy tissue concentration. Additional uncertainties associated with the dioxins/furans BSAFs are discussed in the SRI (Windward and Anchor QEA 2014).

9.3 Site-wide and Area-specific SWAC and Risk Reductions

Risk driver concentrations in sediment following remediation are metrics for evaluating long-term effectiveness and permanence of the alternatives. Estimates of residual risk based on these sediment concentrations provide additional information on long-term effectiveness following remediation. This section summarizes estimates of site-wide and area-specific SWACs and risks over time for each alternative. These model results used the base case chemistry assumptions that were developed and presented in Section 5, based on sensitivity and bounding evaluations described in Appendix J. However, following implementation of the selected remedy, compliance will be determined using a UCL95 rather than a SWAC for area-wide exposure areas.

9.3.1 Reduction in Sediment Bed Concentrations

Tables 9-1a and 9-2 contain the site-wide SWACs predicted using the box model output for total PCBs, dioxins/furans, and arsenic; in addition, SWACs for clamming areas are presented in Tables 9-1b and 9-2 for arsenic and cPAHs, respectively, as they were identified as human health risk drivers for clam consumption (cPAHs) and direct sediment contact during clamming (arsenic). The results are tabulated as a function of time (years 0 to 40), with year 0 being the completion of construction of each alternative (construction durations are also shown on Tables 9-1a, 9-1b, and 9-2 for perspective). The No Action Alternative has no remedial actions but provides a basis to compare the relative effectiveness of the other alternatives.

Time trends of site-wide SWACs from Tables 9-1a, 9-1b, and 9-2 are presented in Figures 9-1a, 9-1b, and 9-1c. Arsenic and cPAH SWACs in clamming areas from Tables 9-1b and 9-2 are shown in Figures 9-2a and 9-2b. Table 9-3 presents predicted percentages of sediment locations below the PRGs for the key benthic risk drivers over time.

The following general observations can be made from information presented in the foregoing tables and figures:

- **RAO 1 (Tables 9-1a and 9-1b; Figures 9-1a, 9-1b, and 9-2b)**
  - At year 40 after construction completion, site-wide SWACs for total PCBs and dioxins/furans are predicted to reach very similar values for Alternatives 1B(12) through 3E(7.5), a consequence of incoming upstream sediment from the Green/Duwamish River and remediation footprints that all emphasize removal. Alternative 1A(12) would take longer than 40 years to approach similar values as the other action alternatives.
  - For the action alternatives, SWACs increase for total PCBs and dioxins/furans from year 0 to 5 (after construction completion) as a result of two key assumptions that result from vessel propwash: 1) mixing of RMC with underlying dredge residuals in portions of the EW, and 2) exchange of resuspended underpier sediments with open-water sediments. The extent of mixing and exchange was approximated in consultation with EPA and may not accurately capture the actual impact to SWAC, but it is an appropriate assumption for the comparison of alternatives in the FS (see Appendix J for vertical mixing and volume exchange assumptions, and sensitivity/bounding evaluations).

Table 9-1a

Predicted Long-term Site-wide SWACs for Risk Drivers for RAOs 1 and 4

Total PCB Site-wide SWACs (μg/kg dw) (RAOs 1 and 4)

Alternative	**Construction Time (years)**	**Site-wide (Seafood Consumption)** Baseline SWAC = 460[a] Human Health PRG (Natural Background) = 2[b] Ecological (Fish) PRG = 250/370[c]								
		Time After Construction (years)								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	604	410	326	281	251	229	210	194	180
1A(12)	9	76	131	126	114	103	95	87	82	77
1B(12)	9	40	71	71	68	65	63	60	59	57
1C+(12)	9	40	65	65	63	61	59	57	56	54
2B(12)	10	42	72	71	68	65	63	60	59	57
2C+(12)	10	42	65	65	63	61	59	57	56	55
3B(12)	10	43	71	71	68	65	63	60	59	57
3C+(12)	10	43	65	65	63	61	59	57	56	55
2C+(7.5)	11	39	63	63	61	59	57	56	55	54
3E(7.5)	13	41	56	56	55	53	52	52	51	50

Dioxin/Furan Site-wide SWACs (ng TEQ/kg dw) (RAO 1)

Alternative	**Construction Time (years)**	**Site-wide (Seafood Consumption)** Baseline Mean = 15.7[d] Human Health PRG (Natural Background) = 2[e]								
		Time After Construction (years)								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	15.0	12.2	10.9	10.1	9.6	9.2	8.9	8.6	8.4
1A(12)	9	4.1	7.0	7.2	7.1	6.9	6.8	6.7	6.6	6.5
1B(12)	9	3.2	5.3	5.6	5.8	5.8	5.9	5.9	5.9	5.9
1C+(12)	9	3.2	5.3	5.7	5.8	5.8	5.9	5.9	5.9	6.0
2B(12)	10	3.2	5.3	5.6	5.7	5.8	5.8	5.9	5.9	5.9
2C+(12)	10	3.2	5.3	5.6	5.8	5.8	5.9	5.9	5.9	5.9
3B(12)	10	3.3	5.2	5.6	5.7	5.8	5.8	5.9	5.9	5.9
3C+(12)	10	3.3	5.2	5.6	5.7	5.8	5.8	5.9	5.9	5.9
2C+(7.5)	11	3.0	5.1	5.5	5.6	5.7	5.7	5.8	5.8	5.8
3E(7.5)	13	3.1	5.1	5.5	5.7	5.8	5.8	5.9	5.9	5.9

Notes:

a. Baseline SWAC based on surface sediment data collected from the EW and calculated on the IDW interpolated total PCB concentrations throughout the waterway, as reported in the SRI (Windward and Anchor QEA 2014).

b. The natural background value presented for total PCBs is the UCL95 using the OSV *Bold* Survey (DMMP 2009) dataset (LDW ROD; EPA 2014). See Section 4 for detailed rationale.

c. Two PRGs have been established in Section 4 based on brown rockfish (250 μg/kg dw) and English sole (370 μg/kg dw).

d. Baseline mean based on subtidal composite surface sediment data collected from the EW for dioxins/furans, as reported in the SRI (Windward and Anchor QEA 2014).

e. PRG presented for dioxins/furans is the natural background value (UCL95, using the OSV Bold Survey [DMMP 2009] dataset [LDW ROD]; EPA 2014). See Section 4 for detailed rationale.

Colored cells indicate achievement of Ecological PRGs for brown rockfish and English sole.

Colored cells indicate achievement of Ecological PRG for brown rockfish.

1. SWACs generated using the box model evaluation. Box model predictions use base case chemistry assumptions that were developed and
2. Chemistry inputs from upstream and lateral, as well as replacement values are presented in Section 5 for total PCBs and dioxins/furans.
3. Year 0 post-construction SWACs are estimated considering the likely widespread placement of clean sand (residuals management cover). The

DMMP – Dredged Material Management Program; EW – East Waterway; FS – Feasibility Study; IDW – inverse distance weighting; LDW – Lower Duwamish Waterway; PRG – preliminary remediation goal; RAO – remedial action objective; ROD – Record of Decision; SRI – Supplemental Remedial Investigation; SWAC – spatially-weighted average concentration; TEQ – toxic equivalent; UCL95 – 95% upper confidence limit on the mean

Table 9-1b
Predicted Long-term Clamming SWACs for cPAHs

cPAH Clamming SWACs (µg TEQ/kg dw) (RAO 1)

Alternative	Construction Time (years)	Clamming Areas Baseline Mean = 1,900[a]								
		Time After Construction (years)								
		0	5	10	15	20	25	30	35	40
No Action	-	1161	527	308	226	195	181	174	169	166
1A(12)	9	19	186	185	176	168	161	157	154	151
1B(12)	9	19	136	146	146	144	143	142	142	141
1C+(12)	9	19	132	143	143	143	142	141	141	140
2B(12)	10	19	136	146	146	144	143	142	142	141
2C+(12)	10	19	132	143	143	143	142	141	141	141
3B(12)	10	28	129	144	145	144	143	142	141	141
3C+(12)	10	28	124	140	142	142	142	141	141	140
2C+(7.5)	11	20	124	136	138	138	138	138	138	138
3E(7.5)	13	28	116	134	138	140	140	140	140	140

Notes:

a. Baseline mean based on area-wide intertidal MIS composite surface sediment data collected from the EW for cPAHs, as reported in the SRI (Windward and Anchor QEA 2014).

1. SWACs are shown for informational purposes. cPAHs are a risk-driver COC for RAO 1 based on consumption of clams. However, a PRG was not developed because the clam tissue-to-sediment relationship for cPAHs in the EW is too uncertain to develop a sediment RBTC based on clam consumption (see Section 3.3.4).

2. SWACs generated using the box model evaluation. Box model predictions use base case chemistry assumptions that were developed and presented in Section 5.

3. Chemistry inputs from upstream and lateral sources, as well as replacement values, are presented in Section 5 for cPAHs.

µg – microgram; DMMP – Dredged Material Management Program; dw – dry weight; EW – East Waterway; IDW – inverse distance weighting; kg – kilogram; mg – milligram; MIS – multi-increment sampling; PRG – preliminary remediation goal; RAO – remedial action objective; RBTC – risk-based threshold concentration; ROD – Record of Decision; SRI – Supplemental Remedial Investigation; SWAC – spatially-weighted average concentration; TEQ – toxic equivalent; UCL95 – 95% upper confidence limit on the mean

Table 9-2
Predicted Long-term Site-wide and Clamming SWACs for Arsenic for RAO 2

Arsenic Site-wide and Clamming SWACs (mg/kg dw) (RAO 2)

		Site-wide Baseline SWAC = 8.8[a] Netfishing PRG (Natural Background) = 7[b]									**Clamming Areas** Baseline Mean = 10[c] Tribal Clamming PRG (Natural Background) = 7[b]								
	Construction Time (years)	**Time After Construction (years)**									**Time After Construction (years)**								
Alternative		**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	10.1	9.8	9.6	9.5	9.5	9.4	9.4	9.3	9.3	9.4	9.3	9.3	9.2	9.2	9.2	9.2	9.1	9.1
1A(12)	9	4.5	7.1	7.7	7.9	8.0	8.1	8.2	8.2	8.3	2.3	8.3	8.8	8.9	8.9	8.9	8.9	8.9	8.9
1B(12)	9	4.4	7.1	7.6	7.8	8.0	8.0	8.1	8.2	8.2	2.3	8.2	8.7	8.8	8.9	8.9	8.9	8.9	8.9
1C+(12)	9	4.4	6.8	7.4	7.7	7.8	7.9	8.0	8.1	8.2	2.3	8.0	8.6	8.8	8.8	8.8	8.8	8.8	8.8
2B(12)	10	4.4	7.0	7.6	7.8	7.9	8.0	8.1	8.2	8.2	2.3	8.2	8.7	8.8	8.9	8.9	8.9	8.9	8.9
2C+(12)	10	4.4	6.8	7.4	7.7	7.8	7.9	8.0	8.1	8.2	2.3	8.0	8.6	8.7	8.8	8.8	8.8	8.8	8.8
3B(12)	10	4.6	6.9	7.5	7.8	7.9	8.0	8.1	8.1	8.2	3.1	7.9	8.6	8.8	8.9	8.9	8.9	8.9	8.9
3C+(12)	10	4.5	6.7	7.3	7.6	7.8	7.9	8.0	8.1	8.2	3.1	7.7	8.5	8.7	8.8	8.8	8.8	8.8	8.8
2C+(7.5)	11	4.3	6.7	7.3	7.6	7.8	7.9	8.0	8.1	8.1	2.3	8.0	8.6	8.7	8.8	8.8	8.8	8.8	8.8
3E(7.5)	13	4.3	6.3	7.1	7.5	7.7	7.9	8.0	8.1	8.2	3.1	7.6	8.4	8.7	8.9	8.9	8.9	9.0	9.0

Notes:

a. Baseline SWACs based on surface sediment data collected from the EW and calculated on the IDW interpolated arsenic concentrations throughout the waterway, as reported in the SRI (Windward and Anchor QEA 2014).

b. The natural background value presented for arsenic is the UCL95 using the OSV *Bold* Survey (DMMP 2009) dataset (LDW ROD; EPA 2014). See Section 4 for detailed rationale.

c. Baseline mean based on area-wide intertidal MIS composite surface sediment data collected from the EW for arsenic as reported in the SRI (Windward and Anchor QEA 2014).

Colored cells indicate achievement of PRGs.

1. SWACs generated using the box model evaluation. Box model predictions use base case chemistry assumptions that were developed and presented in Section 5.

2. Chemistry inputs from upstream and lateral sources, as well as replacement values, are presented in Section 5 for arsenic.

DMMP – Dredged Material Management Program; dw – dry weight; EW – East Waterway; IDW – inverse distance weighting; kg – kilogram; mg – milligram; MIS – multi-increment sampling; PRG – preliminary remediation goal; RAO – remedial action objective; RBTC – risk-based threshold concentration; ROD – Record of Decision; SRI – Supplemental Remedial Investigation; SWAC – spatially-weighted average concentration; TEQ – toxic equivalent; UCL95 – 95% upper confidence limit on the mean

Table 9-3
Predicted Percentages of Sediment Locations Below PRGs and CSL
for Key Benthic Risk Drivers Over Time (RAO 3)

Percent Locations Below PRGs

Alternative	Construction Time (years)	COC	Time After Construction (years)								
			0	5	10	15	20	25	30	35	40
No Action	-	All 7 key benthic risk drivers	22%	nc	nc	nc	nc	nc	nc	nc	nc
1A(12)	9	Mercury	98%	98%	99%	100%	100%	100%	100%	100%	100%
		BEHP	98%	99%	99%	99%	99%	99%	99%	99%	99%
		1,4-DCB	99%	99%	99%	99%	99%	99%	99%	99%	99%
		Total PCBs	96%	96%	97%	97%	97%	97%	98%	98%	99%
		All other key benthic risk drivers	100%	100%	100%	100%	100%	100%	100%	100%	100%
1B(12)	9	All 7 key benthic risk drivers	100%	100%	100%	100%	100%	100%	100%	100%	100%
1C+(12)	9		100%	100%	100%	100%	100%	100%	100%	100%	100%
2B(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
2C+(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
3B(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
3C+(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
2C+(7.5)	11		100%	100%	100%	100%	100%	100%	100%	100%	100%
3E(7.5)	13		100%	100%	100%	100%	100%	100%	100%	100%	100%

Percent Locations Below CSL[a]

Alternative	Construction Time (years)	COC	Time After Construction (years)								
			0	5	10	15	20	25	30	35	40
No Action	-	All 7 key benthic risk drivers	70%	nc	nc	nc	nc	nc	nc	nc	nc
1A(12)	9	Mercury	100%	100%	100%	100%	100%	100%	100%	100%	100%
		BEHP	99%	99%	99%	99%	99%	99%	99%	99%	99%
		1,4-DCB	99%	99%	99%	99%	99%	99%	99%	99%	99%
		Total PCBs	99%	99%	99%	99%	99%	100%	100%	100%	100%
		All other key benthic risk drivers	100%	100%	100%	100%	100%	100%	100%	100%	100%
1B(12)	9	All 7 key benthic risk drivers	100%	100%	100%	100%	100%	100%	100%	100%	100%
1C+(12)	9		100%	100%	100%	100%	100%	100%	100%	100%	100%
2B(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
2C+(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
3B(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
3C+(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
2C+(7.5)	11		100%	100%	100%	100%	100%	100%	100%	100%	100%
3E(7.5)	13		100%	100%	100%	100%	100%	100%	100%	100%	100%

Notes:
a. Presented for informational purposes only.

Colored cells indicate achievement of RAO 3, based on at least 98% of surface sediment locations that are predicted to be below the PRGs or CSL.

1. For the purpose of the FS, predicted compliance of RAO 3 PRGs for the key benthic risk drivers over time is approximated by at least 98% of existing surface locations sediment sample locations with key benthic risk driver COC concentrations predicted to be below the PRGs.

2. Point mixing model evaluation was conducted using seven key benthic risk driver COCs (total PCBs, arsenic, mercury, total HPAHs, total LPAHs, BEHP, and 1,4-dichlorobenzene), which serve as a surrogate for the 29 SMS contaminants identified as benthic invertebrate community COCs in the ERA (Windward 2012a). Total PCBs and arsenic are also human health risk drivers.

3. Concentration predictions use the point mixing model evaluation for key benthic risk driver COCs described in Section 5 in MNR areas (under piers and under bridges, 18 locations). The percent of sediment locations below PRGs and CSL is calculated by dividing the predicted number of surface locations exceeding by the number of FS baseline locations (n = 342 locations), which includes existing surface and shallow subsurface (0-2 ft) sediment sample locations in areas exposed to propeller wash.

4. For Alternative 1A(12), surface sediment locations exceeding the PRGs or the CSL at specific times are presented in Appendix J (Figures 7a and 7b) for key benthic risk driver COCs.

5. For the No Action Alternative, the percentage of sediment locations below PRGs and CSL are presented for existing conditions. Point predictions were not calculated for the No Action Alternative based on the expectation that many of these points will remain above the PRGs in the long term.

1,4-DCB – 1,4-dichlorobenzene; BEHP – bis(2-ethylhexyl)phthalate; COC – contaminant of concern; cPAH – carcinogenic polycyclic aromatic hydrocarbon; CSL – cleanup screening level; ERA – ecological risk assessment; FS – Feasibility Study; HPAH – high-molecular-weight polycyclic aromatic hydrocarbon; LPAH – low-molecular-weight polycyclic aromatic hydrocarbon; MNR – monitored natural recovery; nc – not calculated; PRG – preliminary remediation goal; RAO – remedial action objective; SMS - Sediment Management Standards

- None of the alternatives achieve total PCB and dioxin/furan natural background - based PRGs for the human seafood consumption scenario. However, the action alternatives reduce total PCB SWACs between 87% and 92% at year 40, compared to pre-construction conditions.

- **RAO 2 (Table 9-2; Figures 9-1c and 9-2a)**

  All alternatives, except for No Action, are predicted to meet the natural background-based PRG for arsenic of 7 mg/kg dw (based on the UCL95; LDW ROD 2014) at year 0 (immediately after construction completion [9 to 13 years, depending on the alternative]) for site-wide netfishing and clamming areas. All alternatives, including No Action, may meet this RAO 2 PRG in the long term, depending on incoming sediment concentrations (Section 9.15.1.2).

  - The site-wide and clamming area SWACs for arsenic show an increase when comparing years 0 to 5 (after construction completion) due to the impacts from vessel propwash and the predicted concentration of the incoming lateral and upstream material depositing in the EW that is higher than the predicted surface sediment chemistry at year 0 (after construction completion) for this COC. All action alternative SWACs are below the site-wide and clamming area PRG for arsenic (7 mg/kg dw) immediately after construction, and may also maintain the PRG in the long term, depending on incoming sediment concentrations (Section 9.15.1.2).

- **RAO 3 (Table 9-3)**

  - The No Action Alternative is not expected to achieve the PRGs for RAO 3.
  - Alternative 1A(12) is predicted to achieve the RAO 3 PRG for total PCBs of at least 98% of surface sediment locations below the PRGs by year 30 after construction completion (39 years total, including a 9-year construction time). Other key benthic risk driver COCs are predicted to be below their respective PRGs at year 0 (immediately after construction completion [9 years, including construction time]).
  - Alternatives 1B(12) through 3E(7.5) are predicted to achieve this percentage for all key benthic risk driver COCs at year 0 (immediately after construction completion [9 to 13 years, including construction time, depending on the alternative]).

- **RAO 4: (Table 9-1a; Figure 9-1a)**
  - The No Action Alternative is predicted to achieve the total PCB PRGs for the protection of English sole (370 µg/kg dw) and brown rockfish (250 µg/kg dw) by years 10 and 25, respectively.
  - The action alternatives are predicted to achieve site-wide total PCB SWACs below the PRGs for protection of English sole and brown rockfish at year 0 (immediately after construction completion [9 to 13 years, including construction time, depending on the alternative]).

The box model output plotted in Figures 9-1a, 9-1b, and 9-1c (site-wide SWACs) and Figures 9-2a and 9-2b (clamming area SWACs) are based on chemistry from upstream inputs, lateral inputs, post-construction sediment bed replacement values, EW sediments not remediated, and predicted dredge residuals (see Section 5.2 and Appendix B, Part 3A). The impact of input parameters on the results of the long-term effectiveness and recontamination potential evaluations were addressed through bounding and sensitivity analyses described in Sections 5.3.6 and 5.4.6. The results of these evaluations are discussed in Appendix J. Uncertainties of SWAC predictions are summarized in Section 9.15.

In addition, an uncertainty overview was already provided in Section 5.6, including uncertainty introduced into NSRs, initial deposition of EW lateral sources, chemistry assumptions, high-flow scour potential, and mixing depths due to vessel operations.

9.3.2 Reduction in Tissue Concentrations

Table 9-4 presents predictions of total PCB and dioxin/furan concentrations in fish and shellfish tissue based on predicted site-wide total PCB and dioxin/furan SWACs (estimated with the box model, as discussed in Section 9.2.3). As shown in Table 9-4, total PCB tissue concentrations for all species are predicted to decrease over time (starting at year 5) for all of the alternatives. Dioxin/furan tissue concentrations for all species are predicted to slightly increase after construction over years 5 and 10 and then reach steady concentrations for all of the alternatives.

Table 9-4
Predicted Total PCB and Dioxin/Furan Tissue Concentrations

Total PCBs (µg/kg ww)

Alternative	Construction Time (years)	Clams Baseline UCL = 69 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	140	105	90	81	75	64	61	58	55
1A(12)	9	28	46	45	43	41	32	30	30	29
1B(12)	9	22	27	27	27	26	26	25	25	25
1C+(12)	9	22	26	26	26	26	25	25	25	24
2B(12)	10	22	28	27	27	26	26	25	25	25
2C+(12)	10	22	26	26	26	26	25	25	25	24
3B(12)	10	22	27	27	27	26	26	25	25	25
3C+(12)	10	22	26	26	26	26	25	25	25	24
2C+(7.5)	11	21	26	26	26	25	25	25	24	24
3E(7.5)	13	22	25	25	24	24	24	24	24	24

Alternative	Construction Time (years)	Crab, Whole Body Baseline UCL = 450 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	650	490	420	390	360	300	290	270	260
1A(12)	9	140	220	220	210	200	150	150	140	140
1B(12)	9	110	130	130	130	130	130	130	130	120
1C+(12)	9	110	130	130	130	130	130	120	120	120
2B(12)	10	110	140	130	130	130	130	130	130	120
2C+(12)	10	110	130	130	130	130	130	120	120	120
3B(12)	10	110	130	130	130	130	130	130	130	120
3C+(12)	10	110	130	130	130	130	130	120	120	120
2C+(7.5)	11	110	130	130	130	130	120	120	120	120
3E(7.5)	13	110	120	120	120	120	120	120	120	120

Alternative	Construction Time (years)	Crab, Edible Meat Baseline UCL = 160 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	170	130	110	98	91	77	73	70	67
1A(12)	9	35	56	55	52	50	39	37	36	35
1B(12)	9	27	34	34	33	32	32	31	31	31
1C+(12)	9	27	32	32	32	32	31	31	31	30
2B(12)	10	27	34	34	33	32	32	31	31	31
2C+(12)	10	27	32	32	32	32	31	31	31	30
3B(12)	10	28	34	34	33	32	32	31	31	31
3C+(12)	10	28	32	32	32	32	31	31	31	30
2C+(7.5)	11	27	32	32	32	31	31	31	30	30
3E(7.5)	13	27	31	31	30	30	30	30	29	29

Alternative	Construction Time (years)	Pelagic Fish (shiner surfperch) Baseline UCL = 1,600 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	1800	1350	1140	1020	950	810	760	720	690
1A(12)	9	350	560	550	520	490	400	370	360	350
1B(12)	9	260	330	330	330	320	310	310	300	300
1C+(12)	9	260	320	320	310	310	300	300	300	290
2B(12)	10	260	340	330	330	320	310	310	300	300
2C+(12)	10	260	320	320	310	310	300	300	300	290
3B(12)	10	260	330	330	330	320	310	310	300	300
3C+(12)	10	260	320	320	310	310	300	300	300	290
2C+(7.5)	11	250	310	310	310	300	300	300	290	290
3E(7.5)	13	260	300	300	290	290	290	290	280	280

Alternative	Construction Time (years)	English Sole, whole body Baseline UCL = 4,100 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	2500	1760	1450	1280	1170	1030	960	900	850
1A(12)	9	400	670	650	600	560	470	440	420	410
1B(12)	9	270	380	380	370	360	350	340	340	330
1C+(12)	9	270	360	360	350	350	340	330	330	320
2B(12)	10	280	390	380	370	360	350	340	340	330
2C+(12)	10	280	360	360	350	350	340	330	330	320
3B(12)	10	280	380	380	370	360	350	340	340	330
3C+(12)	10	280	360	360	350	350	340	330	330	320
2C+(7.5)	11	260	350	350	350	340	330	330	320	320
3E(7.5)	13	270	330	330	320	320	310	310	310	310

Alternative	Construction Time (years)	English Sole, fillet Baseline UCL = 2,400 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	1400	1030	850	750	680	600	560	520	490
1A(12)	9	230	390	380	350	330	280	260	250	240
1B(12)	9	160	220	220	220	210	210	200	200	190
1C+(12)	9	160	210	210	210	200	200	190	190	190
2B(12)	10	160	230	220	220	210	210	200	200	190
2C+(12)	10	160	210	210	210	200	200	190	190	190
3B(12)	10	160	220	220	220	210	210	200	200	190
3C+(12)	10	160	210	210	210	200	200	190	190	190
2C+(7.5)	11	150	210	210	200	200	190	190	190	190
3E(7.5)	13	160	190	190	190	180	180	180	180	180

Alternative	Construction Time (years)	Brown Rockfish, whole body Baseline UCL = 4,000 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	3200	2440	2090	1900	1770	1500	1420	1350	1290
1A(12)	9	680	1090	1070	1020	970	760	720	700	680
1B(12)	9	530	660	660	640	630	620	610	610	600
1C+(12)	9	530	630	630	620	610	610	600	590	580
2B(12)	10	530	660	660	640	630	620	610	610	600
2C+(12)	10	530	630	630	620	610	610	600	590	590
3B(12)	10	540	660	660	640	630	620	610	610	600
3C+(12)	10	540	630	630	620	610	610	600	590	590
2C+(7.5)	11	520	620	620	610	610	600	590	590	580
3E(7.5)	13	530	590	590	590	580	580	580	570	570

Table 9-4
Predicted Total PCB and Dioxin/Furan Tissue Concentrations

Dioxins/Furans (ng TEQ/kg ww)

Alternative	Construction Time (years)	Clams Baseline UCL = 0.38 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	ne	ne	ne	ne	ne	ne	ne	ne	ne
1A(12)	9	ne	ne	ne	ne	ne	ne	ne	ne	ne
1B(12)	9	ne	ne	ne	ne	ne	ne	ne	ne	ne
1C+(12)	9	ne	ne	ne	ne	ne	ne	ne	ne	ne
2B(12)	10	ne	ne	ne	ne	ne	ne	ne	ne	ne
2C+(12)	10	ne	ne	ne	ne	ne	ne	ne	ne	ne
3B(12)	10	ne	ne	ne	ne	ne	ne	ne	ne	ne
3C+(12)	10	ne	ne	ne	ne	ne	ne	ne	ne	ne
2C+(7.5)	11	ne	ne	ne	ne	ne	ne	ne	ne	ne
3E(7.5)	13	ne	ne	ne	ne	ne	ne	ne	ne	ne

Alternative	Construction Time (years)	Crab, Whole Body Baseline UCL = 1.3 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	0.98	0.80	0.71	0.66	0.63	0.60	0.58	0.56	0.55
1A(12)	9	0.26	0.46	0.47	0.46	0.45	0.44	0.44	0.43	0.42
1B(12)	9	0.20	0.35	0.37	0.38	0.38	0.39	0.39	0.39	0.39
1C+(12)	9	0.20	0.35	0.37	0.38	0.38	0.39	0.39	0.39	0.39
2B(12)	10	0.20	0.35	0.37	0.37	0.38	0.38	0.39	0.39	0.39
2C+(12)	10	0.20	0.35	0.37	0.38	0.38	0.39	0.39	0.39	0.39
3B(12)	10	0.21	0.34	0.37	0.37	0.38	0.38	0.39	0.39	0.39
3C+(12)	10	0.21	0.34	0.37	0.37	0.38	0.38	0.39	0.39	0.39
2C+(7.5)	11	0.19	0.33	0.36	0.37	0.37	0.37	0.38	0.38	0.38
3E(7.5)	13	0.20	0.33	0.36	0.37	0.38	0.38	0.39	0.39	0.39

Alternative	Construction Time (years)	Crab, Edible Meat Baseline UCL = 0.49 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	0.38	0.31	0.28	0.26	0.24	0.23	0.23	0.22	0.21
1A(12)	9	0.10	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.17
1B(12)	9	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15
1C+(12)	9	0.08	0.13	0.15	0.15	0.15	0.15	0.15	0.15	0.15
2B(12)	10	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15
2C+(12)	10	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15
3B(12)	10	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15
3C+(12)	10	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15
2C+(7.5)	11	0.07	0.13	0.14	0.14	0.15	0.15	0.15	0.15	0.15
3E(7.5)	13	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15

Alternative	Construction Time (years)	Pelagic Fish (shiner surfperch) Baseline UCL = 1.4 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	1.1	0.89	0.80	0.74	0.70	0.67	0.65	0.63	0.61
1A(12)	9	0.29	0.51	0.53	0.52	0.50	0.50	0.49	0.48	0.47
1B(12)	9	0.23	0.39	0.41	0.42	0.42	0.43	0.43	0.43	0.43
1C+(12)	9	0.23	0.39	0.42	0.42	0.42	0.43	0.43	0.43	0.44
2B(12)	10	0.23	0.39	0.41	0.42	0.42	0.42	0.43	0.43	0.43
2C+(12)	10	0.23	0.39	0.41	0.42	0.42	0.43	0.43	0.43	0.43
3B(12)	10	0.23	0.38	0.41	0.42	0.42	0.42	0.43	0.43	0.43
3C+(12)	10	0.23	0.38	0.41	0.42	0.42	0.42	0.43	0.43	0.43
2C+(7.5)	11	0.21	0.37	0.40	0.41	0.42	0.42	0.42	0.42	0.42
3E(7.5)	13	0.22	0.37	0.40	0.42	0.42	0.42	0.43	0.43	0.43

Alternative	Construction Time (years)	English Sole, whole body Baseline UCL = 2.8 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	1.49	1.21	1.08	1.00	0.95	0.91	0.88	0.85	0.83
1A(12)	9	0.40	0.69	0.71	0.70	0.68	0.67	0.66	0.65	0.64
1B(12)	9	0.31	0.53	0.56	0.58	0.58	0.58	0.58	0.58	0.58
1C+(12)	9	0.31	0.53	0.57	0.58	0.58	0.58	0.58	0.58	0.59
2B(12)	10	0.31	0.53	0.56	0.57	0.58	0.58	0.58	0.58	0.58
2C+(12)	10	0.31	0.53	0.56	0.58	0.58	0.58	0.58	0.58	0.58
3B(12)	10	0.32	0.52	0.56	0.57	0.58	0.58	0.58	0.58	0.58
3C+(12)	10	0.32	0.52	0.56	0.57	0.58	0.58	0.58	0.58	0.58
2C+(7.5)	11	0.29	0.51	0.55	0.56	0.57	0.57	0.58	0.58	0.58
3E(7.5)	13	0.30	0.51	0.55	0.57	0.58	0.58	0.58	0.58	0.58

Alternative	Construction Time (years)	English Sole, fillet Baseline UCL = 0.79 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	0.64	0.52	0.46	0.43	0.41	0.39	0.38	0.37	0.36
1A(12)	9	0.17	0.30	0.31	0.30	0.29	0.29	0.29	0.28	0.28
1B(12)	9	0.13	0.23	0.24	0.25	0.25	0.25	0.25	0.25	0.25
1C+(12)	9	0.13	0.23	0.24	0.25	0.25	0.25	0.25	0.25	0.26
2B(12)	10	0.13	0.23	0.24	0.24	0.25	0.25	0.25	0.25	0.25
2C+(12)	10	0.13	0.23	0.24	0.25	0.25	0.25	0.25	0.25	0.25
3B(12)	10	0.14	0.22	0.24	0.24	0.25	0.25	0.25	0.25	0.25
3C+(12)	10	0.14	0.22	0.24	0.24	0.25	0.25	0.25	0.25	0.25
2C+(7.5)	11	0.12	0.22	0.23	0.24	0.24	0.24	0.25	0.25	0.25
3E(7.5)	13	0.13	0.22	0.23	0.24	0.25	0.25	0.25	0.25	0.25

Alternative	Construction Time (years)	Brown Rockfish, whole body Baseline UCL = 2.8 Time After Construction (years): 0	5	10	15	20	25	30	35	40
No Action	-	1.97	1.60	1.43	1.33	1.26	1.21	1.17	1.13	1.10
1A(12)	9	0.53	0.92	0.95	0.93	0.91	0.89	0.88	0.87	0.85
1B(12)	9	0.41	0.70	0.74	0.76	0.76	0.78	0.78	0.78	0.78
1C+(12)	9	0.41	0.70	0.75	0.76	0.76	0.78	0.78	0.78	0.79
2B(12)	10	0.41	0.70	0.74	0.75	0.76	0.76	0.78	0.78	0.78
2C+(12)	10	0.41	0.70	0.74	0.76	0.76	0.78	0.78	0.78	0.78
3B(12)	10	0.42	0.68	0.74	0.75	0.76	0.76	0.78	0.78	0.78
3C+(12)	10	0.42	0.68	0.74	0.75	0.76	0.76	0.78	0.78	0.78
2C+(7.5)	11	0.38	0.67	0.72	0.74	0.75	0.75	0.76	0.76	0.76
3E(7.5)	13	0.39	0.67	0.72	0.75	0.76	0.76	0.78	0.78	0.78

Notes:

1. Total PCB tissue concentrations were estimated with the FWM (Anchor QEA and Windward 2014) using the alternative-specific total PCB SWACs in sediment (Table 9-1) and assumed surface water dissolved total PCB concentrations of 0.6 ng/L (except 0.9 ng/L for the No Action Alternative [at years 20 to 40] and for Alternative 1A(12) [years 5 to 20], and 1.2 ng/L for the No Action Alternative [at years 0 to 20]).
2. Dioxin/furan tissue concentrations were estimated with BSAFs (Anchor QEA and Windward 2014) using the alternative-specific dioxin/furan SWACs in sediment (Table 9-1).
3. Baseline tissue concentrations based on UCL95 using actual tissue data collected from the EW, as reported in the HHRA (Windward 2012b). UCL95 is the selected statistic for baseline tissue concentrations consistent with the HHRA. For comparative purposes, year 0 tissue concentrations estimates for the No Action Alternative were calculated using the FWM and BSAFs and total PCB and dioxin/furan SWACs using the FS baseline dataset. Therefore, these differ from the HHRA baseline tissue concentrations. Post-remediation tissue concentrations (UCL95) will be compared to the baseline concentrations (UCL95).
4. No mussel or geoduck data could be predicted for total PCBs or dioxins/furans, nor clam data for dioxins/furans.
5. All tissue concentrations have been rounded to two significant figures.

µg – microgram; BSAF – biota-sediment accumulation factor; EW – East Waterway; FS – Feasibility Study; FWM – food web model; HHRA – human health risk assessment; kg – kilogram; L – liter; ne – not estimated; ng – nanogram; PCB – polychlorinated biphenyl; SWAC – spatially-weighted average concentration; TEQ – toxic equivalent; UCL95 – 95% upper confidence limit on the mean; ww – wet weight

Because the long-term sediment concentrations are relatively similar across Alternatives 1B(12) through 3E(7.5), the predicted total PCB and dioxin/furan tissue concentrations are also similar across these alternatives at any given time. For example, 40 years after the completion of construction, Alternatives 1B(12) through 3E(7.5) are predicted to achieve whole body English sole concentrations of approximately 310 to 330 µg/kg ww for total PCBs and 0.58 ng TEQ/kg ww for dioxins/furans. Predicted total PCB and dioxin/furan tissue concentrations for Alternative 1A(12) are slightly higher for many species than the ones for the other action alternatives during the first 15 years (Table 9-1a).

Uncertainties associated with the tissue concentrations predictions for total PCBs and dioxins/furans are discussed in Section 9.15. Additionally, uncertainties associated with the FWM and the BSAFs are discussed in detail in the SRI (Windward and Anchor QEA 2014).

9.3.3 Reduction in Risks for Human Health

The SWAC predictions discussed above can be used to estimate the human health risks associated with seafood consumption for total PCBs and dioxins/furans (RAO 1) and the risks associated with direct sediment exposure for arsenic (RAO 2). These estimates are used in the FS as milestone metrics for the comparison of alternatives.

9.3.3.1 Risks Associated with Seafood Consumption

Excess cancer risks and non-cancer HQs for total PCBs and dioxins/furans associated with the consumption of resident seafood from the EW were estimated for each of the alternatives at various time points following their implementation. Risks for the other human health seafood consumption risk driver, cPAHs, were largely based on consumption of clams. As noted in Section 3.3.4, it was not possible to predict clam tissue concentrations following remediation.

Excess Cancer Risks

Table 9-5a presents the lifetime individual excess cancer risks for each alternative for the three RME seafood consumption scenarios evaluated in the SRI for total PCBs and dioxins/furans. Calculated risks are shown at various time increments, starting from the end of construction (year 0) and continuing at 5-year intervals through year 40. Color shading in this table indicates the magnitude of the calculated individual excess cancer risk. Figures 9-3a and 9-3b show the predicted post-remedy total PCB and dioxin/furan seafood consumption risks, respectively, for the Adult Tribal RME scenario at years 0, 5, and 40 (after construction completion) for each alternative.

As shown in these figures, the predicted individual excess cancer risks for the Adult Tribal RME seafood consumption scenario are similar for the action alternatives 40 years after construction completion (equal to 2×10^{-4} for total PCBs and 5×10^{-5} for dioxins/furans). The predicted post-remedy individual excess cancer risks for the No Action Alternative for the Adult Tribal RME scenario are slightly higher, equal to 4×10^{-4} for total PCBs and 7×10^{-5} for dioxins/furans.

Individual excess cancer risks are also predicted to be similar in the long term (40 years after construction completion) across alternatives for the Child Tribal RME scenario (risks of 3×10^{-5} to 8×10^{-5} for total PCBs and 8×10^{-6} to 1×10^{-5} for dioxins/furans) and the Adult API RME scenario (risks of 7×10^{-5} to 2×10^{-4} for total PCBs, and 2×10^{-5} to 3×10^{-5} for dioxins/furans).

Total excess cancer risks for the seafood consumption scenarios (i.e., the sum of risks for total PCBs and dioxins/furans[110]) are in the 10^{-4} order of magnitude for the Adult Tribal and API RME scenarios (for the action alternatives) and in the 10^{-5} order of magnitude for the Child Tribal RME scenarios (for Alternatives 1B(12) through 3E(7.5); Table 9-5b). Figure 9-4 shows the predicted total excess cancer risks for the Adult Tribal RME seafood consumption scenario at years 0, 5, and 40 after construction completion for each alternative. The percent risk reduction in total excess cancer risk for the action alternatives is between 70% and 80% for the three RME scenarios.

Non-Cancer Hazard Quotients

Similar to Table 9-5a, Table 9-5c presents the non-cancer HQs for the RME seafood consumption scenarios for total PCBs and dioxins/furans.[111] For total PCBs, HQs for all three

[110] As previously discussed, it was not possible to calculate post-remedy risks for cPAHs (the other seafood consumption scenario risk driver), and thus cPAHs are not included in this sum.

[111] A hazard quotient (HQ) is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected. If the HQ is calculated to be equal to or less than 1, then no adverse health effects are expected as a result of exposure. If the HQ is greater than 1, then adverse health effects are possible. The hazard index (HI) is the sum of more than one HQ for multiple substances with similar modes of toxic action (e.g., total PCBs plus dioxins/furans).

RME scenarios are predicted to remain above 1 for all of the alternatives for the HQs calculated based on the immunological/integumentary/neurological endpoints. For the HQs based on the total PCB developmental endpoint, Alternative 1A(12) achieves an HQ of 2 for Adult Tribal, 3 for Child Tribal, and 1 for Adult API RME scenarios 40 years after construction completion. The other action alternatives achieve an HQ of 1 for Adult Tribal, 3 for Child Tribal, and 1 for Adult API RME scenarios 40 years after construction completion. For dioxins/furans, HQs at year 40 are predicted to be equal to or less than 1 for all action alternatives for the Adult Tribal, Child Tribal, and Adult API RME scenarios. Figures 9-5a and 9-5b show the non-cancer HQs associated with residual total PCBs and dioxins/furans at years 0, 5, and 40 after construction completion for each alternative and for the Adult Tribal RME scenario.

In addition to calculating the HQs for the individual risk driver chemicals, the calculation of non-cancer HIs was also considered. Only the HI for the developmental endpoint is presented (Table 9-5d) because no other endpoints include both risk driver chemicals. The HI, which includes the HQ for dioxins/furans and the HQ for total PCBs based on the developmental endpoints, is predicted to be above 1 for all scenarios and alternatives at year 40 after construction completion. It should be noted that total PCBs account for 71% to 88% of this HI sum.

9.3.3.2 Risks Associated with Direct Sediment Exposure

Excess cancer risks for the direct sediment exposure scenarios are presented in Table 9-6.[112] Individual arsenic excess cancer risks for all alternatives are above the 1×10^{-6} threshold for the netfishing and tribal clamming direct contact exposure scenarios. This result was expected because the 1×10^{-6} threshold is below the natural background concentrations for arsenic (see Section 4.4).

At year 0 (immediately after the completion of construction [9 to 13 years, depending on the alternative]), the total excess cancer risk (i.e., excess cancer risks for the direct contact risk driver arsenic) is equal to 1×10^{-5} or less for both the netfishing and tribal clamming scenarios for all alternatives (except the No Action Alternative at year 0 for tribal clamming

[112] Non-cancer HQs were less than one at baseline conditions (year 0), so post-remedy non-cancer HQs were not calculated for the direct sediment exposure RME scenarios because they would also be less than one.

scenario; Table 9-6). Figure 9-6 shows the total risks for both direct sediment exposure scenarios for all alternatives at years 0, 5, and 40 after construction completion.

9.3.4 Reduction in Risks for Ecological Receptors

Total PCBs was identified as a risk driver COC for English sole and brown rockfish based on the tissue residue evaluation. Thus, Table 9-7 presents the post-remedy HQs calculated using FWM-predicted tissue concentrations, based on both of the LOAEL TRVs evaluated in the ERA (LOAEL TRVs of 520 and 2,640 µg/kg ww). Two LOAEL TRVs were presented because of the considerable uncertainty in the study from which the TRVs were derived, as is discussed in both the effects section (Section A.4.2.1.3) and uncertainty section (Section A.6.2.2.2) of the ERA (Windward 2012a). The use of the lower of these TRVs (520 µg/kg ww) likely overestimates risks to these receptors.

The following summarizes the post-remedial HQs:[113]

- **English sole:** HQs are below the threshold of 1.0 using the LOAEL TRV of 2,640 µg/kg ww, with the exception of year 0 for the No Action Alternative. HQs are below the threshold of 1.0 for all years post-construction using LOAEL TRV of 520 µg/kg ww, with the exception of the No Action Alternative and Alternative 1A(12). Alternative 1A(12) is below the threshold of 1.0 LOAEL TRV of 520 µg/kg ww following construction but then is predicted to be slightly above 1.0 (ranging from 1.1 to 1.3) for years 5 through 20 and then is equal to or decreases below 1.0 after this time. The No Action alternative remains above HQ of 1.0 using a LOAEL TRV of 520 µg/kg ww.
- **Brown rockfish:** HQs are below the threshold of 1.0 (with the exception of year 0 for the No Action Alternative) using the LOAEL TRV of 2,640 µg/kg ww. HQs are slightly above 1.0 (ranging from 1.1 to 1.3) for Alternatives 1B(12) through 3E(7.5), with the exception of year 0, when using the LOAEL TRV of 520 µg/kg ww. The HQs for the No Action and Alternative 1A(12) are always greater than 2.5 and 1.3, respectively, for this LOAEL TRV.[114]

[113] The PRGs for RAO 4 are achieved for all action alternatives. HQs are predicted to be above 1.0 for some years due to the influence of water assumptions in the FWM.
[114] HQs predicted to exceed the threshold of 1.0 are due to the water assumptions used in the FWM. Because of uncertainty with these water assumptions, monitoring of fish tissue after remedy completion may be below the lower TRV value.

Table 9-5a

Estimated Individual Excess Cancer Risks for RME Seafood Consumption Scenarios Based on Predicted Long-term Site-wide Total PCB and Dioxin/Furan SWACs

Total PCBs

		Adult Tribal RME Baseline Risk = 1 x 10^{-3}									Child Tribal RME Baseline Risk = 2 x 10^{-4}									Adult API RME Baseline Risk = 4 x 10^{-4}								
		Time After Construction (years)									Time After Construction (years)									Time After Construction (years)								
Alternative	**Construction Time (years)**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	1E-03	8E-04	7E-04	6E-04	6E-04	5E-04	5E-04	4E-04	4E-04	2E-04	2E-04	1E-04	1E-04	1E-04	9E-05	9E-05	8E-05	8E-05	4E-04	3E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04
1A(12)	9	2E-04	3E-04	3E-04	3E-04	3E-04	2E-04	2E-04	2E-04	2E-04	4E-05	6E-05	6E-05	6E-05	6E-05	4E-05	4E-05	4E-05	4E-05	8E-05	1E-04	1E-04	1E-04	1E-04	9E-05	9E-05	8E-05	8E-05
1B(12)	9	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05
1C+(12)	9	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05
2B(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05
2C+(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05
3B(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05
3C+(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05
2C+(7.5)	11	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	3E-05	3E-05	6E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05
3E(7.5)	13	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	6E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05

Dioxins/Furans

		Adult Tribal RME Baseline Risk = 1 x 10^{-4}									Child Tribal RME Baseline Risk = 2 x 10^{-5}									Adult API RME Baseline Risk = 4 x 10^{-5}								
		Time After Construction (years)									Time After Construction (years)									Time After Construction (years)								
Alternative	**Construction Time (years)**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	1E-04	9E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05	7E-05	2E-05	2E-05	2E-05	1E-05	1E-05	1E-05	1E-05	1E-05	1E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	3E-05	3E-05
1A(12)	9	3E-05	5E-05	6E-05	6E-05	5E-05	5E-05	5E-05	5E-05	5E-05	6E-06	1E-05	1E-05	1E-05	1E-05	1E-05	1E-05	9E-06	9E-06	1E-05	2E-05	3E-05	3E-05	2E-05	2E-05	2E-05	2E-05	2E-05
1B(12)	9	2E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	5E-05	4E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
1C+(12)	9	2E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	5E-05	4E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	9E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
2B(12)	10	2E-05	4E-05	4E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	4E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
2C+(12)	10	2E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	5E-05	4E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
3B(12)	10	2E-05	4E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	5E-06	7E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
3C+(12)	10	2E-05	4E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	5E-06	7E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
2C+(7.5)	11	2E-05	4E-05	4E-05	4E-05	4E-05	4E-05	5E-05	5E-05	5E-05	4E-06	7E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
3E(7.5)	13	2E-05	4E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	4E-06	7E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05

Notes:

1. Baseline human health seafood consumption risks are based on tissue data collected from the EW, as reported in the HHRA (Windward 2012b). HHRA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
2. Total PCB excess cancer risks were estimated using tissue concentrations predicted by the FWM (Anchor QEA and Windward 2014) with alternative-specific total PCB SWACs in surface sediment (Table 9-1) and assumed surface water dissolved total PCB concentrations of 0.6 ng/L (except 0.9 ng/L for the No Action Alternative [at years 20 to 40] and for Alternative 1A(12) [years 5 to 20], and 1.2 ng/L for the No Action Alternative [at years 0 to 20]).
3. Dioxin/furan excess cancer risks were estimated using tissue concentrations predicted by BSAFs (Anchor QEA and Windward 2014) with alternative-specific total PCB SWACs in surface sediment (Table 9-1).
4. No mussel or geoduck data could be predicted for total PCBs or dioxins/furans, nor clam data for dioxins/furans. The portion of the diets assigned to these diet items were distributed proportionally to the remaining dietary items.
5. Significant figures are displayed in accordance with the conventions established in the HHRA.
6. Year 0 post-construction risks are estimated considering the likely widespread placement of clean sand (residuals management cover). The increase in risks from year 0 post-construction to year 5 is due to the influences of upstream sediment, lateral loads, vertical mixing of sediment within the waterway, and exchange of sediment between underpier and open-water areas.

10^{-3}	Colored cells indicate estimated excess cancer risk rounded to the nearest order of magnitude.
10^{-4}	
10^{-5}	
10^{-6}	

API – Asian and Pacific Islanders; BSAF – biota-sediment accumulation factor; EW – East Waterway; FWM – food web model; HHRA – human health risk assessment; ng/L – nanogram per liter; PCB – polychlorinated biphenyl; RME – reasonable maximum exposure; SWAC – spatially-weighted average concentration

Table 9-5b

Estimated Total Excess Cancer Risks for RME Seafood Consumption Scenarios Based on Predicted Long-term Site-wide Total PCB and Dioxin/Furan SWACs

Alternative	Construction Time (years)	Adult Tribal RME Baseline Risk = 1 x 10^{-3}									Child Tribal RME Baseline Risk = 2 x 10^{-4}									Adult API RME Baseline Risk = 4 x 10^{-4}								
		Time After Construction (years)									**Time After Construction (years)**									**Time After Construction (years)**								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	1E-03	9E-04	8E-04	7E-04	7E-04	6E-04	5E-04	5E-04	5E-04	2E-04	2E-04	1E-04	1E-04	1E-04	1E-04	1E-04	9E-05	9E-05	4E-04	3E-04	3E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04
1A(12)	9	2E-04	4E-04	4E-04	4E-04	4E-04	3E-04	3E-04	3E-04	3E-04	5E-05	7E-05	7E-05	7E-05	7E-05	5E-05	5E-05	5E-05	5E-05	1E-04	2E-04	2E-04	1E-04	1E-04	1E-04	1E-04	1E-04	1E-04
1B(12)	9	2E-04	2E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	5E-05	5E-05	5E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	1E-04	1E-04	1E-04	1E-04	1E-04	9E-05	9E-05	9E-05
1C+(12)	9	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	9E-05	1E-04	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05
2B(12)	10	2E-04	3E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	5E-05	5E-05	5E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	1E-04	1E-04	1E-04	1E-04	9E-05	9E-05	9E-05	9E-05
2C+(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	9E-05	1E-04	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05
3B(12)	10	2E-04	2E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	5E-05	5E-05	5E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	1E-04	1E-04	1E-04	1E-04	9E-05	9E-05	9E-05	9E-05
3C+(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	9E-05	1E-04	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05
2C+(7.5)	11	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05
3E(7.5)	13	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05

Notes:

1. Baseline human health seafood consumption risks based on tissue data collected from the EW, as reported in the HHRA (Windward 2012b). HHRA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
2. Total excess cancer risks include only the risk drivers for the seafood consumption exposure scenario (total PCBs, dioxins/furans). See Table 9-5a for estimated individual excess cancer risks.
3. Significant figures are displayed in accordance with the conventions established in the HHRA.

10^{-3}	Colored cells indicate estimated excess cancer risk rounded to the nearest order of magnitude.
10^{-4}	
10^{-5}	

API – Asian and Pacific Islanders; EW – East Waterway; HHRA – human health risk assessment; PCB – polychlorinated biphenyl; RME – reasonable maximum exposure; SWAC – spatially-weighted average concentration

Table 9-5c
Estimated Non-cancer Hazard Quotients for RME Seafood Consumption Scenarios Based on Predicted Long-term Site-wide Total PCB and Dioxin/Furan SWACs

Total PCBs (based on the immunological, integumentary, or neurological endpoints)

Alternative	Construction Time (years)	Adult Tribal RME Baseline HQ = 27									Child Tribal RME Baseline HQ = 58									Adult API RME Baseline HQ = 24								
		Time After Construction (years)									Time After Construction (years)									Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	27	21	18	16	15	13	12	11	11	58	45	38	34	31	27	25	24	23	24	18	15	14	13	11	10	10	9
1A(12)	9	5	9	9	8	8	6	6	6	5	12	19	18	17	16	13	12	12	12	5	8	7	7	7	5	5	5	5
1B(12)	9	4	5	5	5	5	5	5	5	5	9	11	11	11	11	10	10	10	10	4	5	5	4	4	4	4	4	4
1C+(12)	9	4	5	5	5	5	5	5	5	5	9	11	11	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4
2B(12)	10	4	5	5	5	5	5	5	5	5	9	11	11	11	11	10	10	10	10	4	5	5	4	4	4	4	4	4
2C+(12)	10	4	5	5	5	5	5	5	5	5	9	11	11	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4
3B(12)	10	4	5	5	5	5	5	5	5	5	9	11	11	11	11	10	10	10	10	4	5	5	4	4	4	4	4	4
3C+(12)	10	4	5	5	5	5	5	5	5	5	9	11	11	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4
2C+(7.5)	11	4	5	5	5	5	5	5	5	5	8	10	10	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4
3E(7.5)	13	4	5	5	5	4	4	4	4	4	9	10	10	10	10	10	10	9	9	4	4	4	4	4	4	4	4	4

Total PCBs (based on the developmental endpoint)

Alternative	Construction Time (years)	Adult Tribal RME Baseline HQ = 8									Child Tribal RME Baseline HQ = 17									Adult API RME Baseline HQ = 7								
		Time After Construction (years)									Time After Construction (years)									Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	8	6	5	5	4	4	3	3	3	17	13	11	10	9	8	7	7	7	7	5	4	4	4	3	3	3	3
1A(12)	9	2	2	2	2	2	2	2	2	2	3	5	5	5	5	4	4	3	3	≤1	2	2	2	2	2	≤1	≤1	≤1
1B(12)	9	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
1C+(12)	9	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2B(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2C+(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3B(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	3	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3C+(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	3	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2C+(7.5)	11	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3E(7.5)	13	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1

Dioxins/Furans (based on the developmental endpoint)

Alternative	Construction Time (years)	Adult Tribal RME Baseline HQ = 1									Child Tribal RME Baseline HQ = 2									Adult API RME Baseline HQ = 0.9								
		Time After Construction (years)									Time After Construction (years)									Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	2	2	2	2	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
1A(12)	9	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
1B(12)	9	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
1C+(12)	9	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2B(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2C+(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3B(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3C+(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2C+(7.5)	11	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3E(7.5)	13	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1

Notes:

1. Baseline human health seafood consumption hazard quotients based on tissue data collected from the EW, as reported in the HHRA (Windward 2012b). HHRA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
2. Total PCB non-cancer hazard quotients were estimated using tissue concentrations predicted by the FWM (Anchor and Windward 2014) with alternative-specific total PCB SWACs in surface sediment (Table 9-1) and assumed surface water dissolved total PCBs concentrations of 0.6 ng/L(except 0.9 ng/L for the No Action Alternative [at years 20 to 40] and for Alternative 1A(12) [years 5 to 20], and 1.2 ng/L for the No Action Alternative [at years 0 to 20]).
3. Dioxin/furan non-cancer hazard quotients were estimated using tissue concentrations predicted by biota-sediment accumulation factors (Anchor QEA and Windward 2014) with alternative-specific total PCB SWACs in surface sediment (Table 9-1).
4. No mussel or geoduck data could be predicted for total PCBs or dioxins/furans, nor clam data for dioxins/furans. The portion of the diets assigned to these diet items were distributed proportionally to the remaining dietary items.
5. All tabulated values are hazard quotients. HQs are rounded following the conventions established in the HHRA (Windward 2012b).

HQ >1	Colored cells indicate estimated non-cancer hazard quotient.
HQ ≤1	

API – Asian and Pacific Islanders; EW – East Waterway; FWM – food web model; HHRA – human health risk assessment; HQ – hazard quotient; ng/L – nanogram per liter; PCB – polychlorinated biphenyl; RME – reasonable maximum exposure; SWAC – spatially-weighted average concentration

Table 9-5d
Estimated Non-cancer Developmental Hazard Index for RME Seafood Consumption Scenarios Based on Predicted Long-term Site-wide Total PCB and Dioxin/Furan SWACs

Total PCBs and Dioxins/Furans (based on the developmental endpoint)

		Adult Tribal RME Baseline HI = 9									**Child Tribal RME** Baseline HI = 19									**Adult API RME** Baseline HI = 8								
	Construction Time (years)	**Time After Construction (years)**									**Time After Construction (years)**									**Time After Construction (years)**								
Alternative		**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	9	7	6	5	5	4	4	4	4	19	15	12	11	10	9	9	8	8	8	6	5	5	4	4	4	3	3
1A(12)	9	2	3	3	3	3	2	2	2	2	4	6	6	6	6	5	5	4	4	2	3	3	3	2	2	2	2	2
1B(12)	9	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
1C+(12)	9	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
2B(12)	10	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
2C+(12)	10	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
3B(12)	10	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
3C+(12)	10	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
2C+(7.5)	11	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
3E(7.5)	13	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2

Notes:

1. Baseline human health seafood consumption hazard index based on tissue data collected from the EW, as reported in the HHRA (Windward 2012b). HHRA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
2. The developmental hazard index is equal to the sum of total PCBs and dioxins/furans based on the developmental endpoint. See Table 9-5c for estimated individual non-cancer hazard quotients.
3. All tabulated values are hazard indices. HIs are rounded following the conventions established in the HHRA (Windward 2012b).

HI >1	Colored cells indicate estimated non-cancer hazard index.
HI ≤1	

API – Asian and Pacific Islanders; EW – East Waterway; HI – hazard index; HHRA – human health risk assessment; PCB – polychlorinated biphenyl; RME – reasonable maximum exposure; SWAC – spatially-weighted average concentration

Table 9-6
Estimated Individual Excess Cancer Risks for Direct Contact Based on Predicted Long-term Site-wide and Clamming Arsenic SWACs

Arsenic

Alternative	Construction Time (years)	Site-wide Netfishing Baseline Risk = 3 x 10^{-6}									Tribal Clamming Baseline Risk = 1 x 10^{-5}								
		Time After Construction (years)									Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	3E-06	3E-06	3E-06	3E-06	3E-06	3E-06	3E-06	3E-06	3E-06	1E-05	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
1A(12)	9	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
1B(12)	9	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
1C+(12)	9	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
2B(12)	10	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
2C+(12)	10	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
3B(12)	10	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
3C+(12)	10	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
2C+(7.5)	11	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
3E(7.5)	13	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06

Notes:

1. Baseline direct contact risks based on data collected from the EW, as reported in the HHRA (Windward 2012b). HHRA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
2. Arsenic risk estimates are based on SWACs for netfishing and tribal clamming areas for each alternative (Table 9-2).
3. Significant figures are displayed in accordance with the conventions established in the HHRA (Windward 2012b).
4. Year 0 post-construction risks are estimated considering the likely widespread placement of clean sand (residuals management cover). The increase in risks from year 0 post-construction to year 5 is due to the influences of upstream sediment, lateral loads, vertical mixing of sediment within the waterway, and exchange of sediment between underpier and open-water areas.

> 1 x 10^{-6}
≤ 1 x 10^{-6}

EW – East Waterway; HHRA – human health risk assessment; SWAC – spatially-weighted average concentration

Table 9-7
Estimated Hazard Quotients for Fish Based on Long-term Site-wide Total PCB SWACs

Using LOAEL TRV of 520 µg/kg ww

		English Sole Baseline HQ = 7.9									Brown Rockfish Baseline HQ = 0.77 to 12								
	Construction Time	Time After Construction (years)									Time After Construction (years)								
Alternative	(years)	0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	7.9	3.4	2.8	2.5	2.3	2.0	1.8	1.7	1.6	12	4.7	4.0	3.6	3.4	2.9	2.7	2.6	2.5
1A(12)	9	≤ 1.0	1.3	1.2	1.2	1.1	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.3	2.1	2.0	2.0	1.9	1.5	1.4	1.4	1.3
1B(12)	9	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.1
1C+(12)	9	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1
2B(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.1
2C+(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1
3B(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.1
3C+(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1
2C+(7.5)	11	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1
3E(7.5)	13	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1

Using LOAEL TRV of 2,640 µg/kg ww

		English Sole Baseline HQ = 1.6									Brown Rockfish Baseline HQ = 0.15 to 2.3								
	Construction Time	Time After Construction (years)									Time After Construction (years)								
Alternative	(years)	0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	1.6	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	2.3	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
1A(12)	9	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
1B(12)	9	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
1C+(12)	9	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
2B(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
2C+(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
3B(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
3C+(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
2C+(7.5)	11	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
3E(7.5)	13	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0

Notes:

1. Total PCB hazard quotients were estimated using tissue concentrations predicted by the FWM (Anchor QEA and Windward 2014) with alternative-specific total PCB SWACs in surface sediment (Table 9-1) and assumed surface water dissolved total PCBs concentrations of 0.6 ng/L (except 0.9 ng/L for the No Action Alternative [at years 20 to 40] and for Alternative 1A(12) [years 5 to 20], and 1.2 ng/L for the No Action Alternative [at years 0 to 20]).
2. Baseline ecological risks for fish are based on whole-body tissue data collected from the EW, as reported in the ERA (Windward 2012a). ERA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
3. The use of two LOAEL TRVs was done because of the considerable uncertainty in the study from which the TRVs were derived, as is discussed in both the effects section (Section A.4.2.1.3) and uncertainty section (Section A.6.2.2.2) of the ERA (Windward 2012a). The use of the lower of these TRVs (520 µg/kg ww) likely overestimates risks to these receptors.
4. All tabulated values are hazard quotients. HQs are rounded following the conventions established in the ERA (Windward 2012a).

HQ >1.0	Colored cells indicate estimated hazard quotient.
HQ ≤1.0	

µg/kg – microgram per kilogram; ERA – ecological risk assessment; EW - East Waterway; FWM – food web model; HQ – hazard quotient; LOAEL – lowest-observed-adverse-effect level; ng/L – nanogram per liter; PCB – polychlorinated biphenyl; SWAC – spatially-weighted average concentration; TRV – toxicity reference value; ww – wet weight

9.4 No Action Alternative

The No Action Alternative is required as part of the CERCLA process. This alternative provides a basis to compare the relative effectiveness of the other alternatives (see Section 10).

9.4.1 Overall Protection of Human Health and the Environment

No project-specific engineering or institutional controls are assumed for this alternative. Therefore, reduction of contaminant concentrations and risks will occur only to the degree achieved by ongoing natural recovery processes and will be tracked with a site-wide long-term monitoring program.

Predictions for the No Action Alternative have the highest uncertainty because it includes no sediment remediation and therefore, all existing surface and subsurface sediment contamination remain in place.

The No Action Alternative is expected to provide limited protection of human health and the environment, and it does not comprise any provisions for site-wide institutional controls to manage residual risks. A description of PRG achievements for the No Action Alternative is listed below (Table 9-8):

- The No Action Alternative does not achieve the natural background PRGs for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO. This alternative is predicted to reduce site-wide total excess cancer risks (for total PCBs and dioxins/furans combined) between 50% and 55% in 40 years, depending on the RME scenario.
- For human health direct contact (RAO 2) for arsenic, this alternative is not predicted to meet the natural background-based RAO 2 PRG for arsenic of 7 mg/kg dw, but may achieve this value in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2).
- This alternative is not expected to achieve the RAO 3 PRGs because most of the surface sediment locations are predicted to remain above the PRGs for all seven key benthic risk driver COCs; only 22% of the locations are below the PRGs.[115]

[115] Point predictions for compliance with RAO 3 PRGs were not conducted in the long term for the No Action Alternative.

Table 9-8
Model-predicted Times to Achieve Evaluation Metrics for Remedial Action Objectives

Remedial Action Objective and Evaluation Metric	Risk Driver	Time to Achieve Objective or Evaluation Metric (Years from the Start of Construction)[a]									
		Alternative (Construction Time)									
		No Action (-)	1A(12) (9 years)	1B(12) (9 years)	1C+(12) (9 years)	2B(12) (10 years)	2C+(12) (10 years)	3B(12) (10 years)	3C+(12) (10 years)	2C+(7.5) (11 years)	3E(7.5) (13 years)
RAO 1 - Human Health (Seafood Consumption)											
10^{-4} Order of Magnitude Cancer Risk for Adult Tribal RME	Total PCBs	35	9[b]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
	Dioxins/Furans	0 (achieves at baseline conditions or start of construction)									
10^{-5} Order of Magnitude Cancer Risk for Child Tribal RME	Total PCBs	Does not achieve.	34	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
	Dioxins/Furans	0 (achieves at baseline conditions or start of construction)									
10^{-4} Order of Magnitude Cancer Risk for Adult API RME	Total PCBs	0 (achieves at baseline conditions or start of construction)									
	Dioxins/Furans	0 (achieves at baseline conditions or start of construction)									
10^{-5} Order of Magnitude Cancer Risk for Adult API RME	Total PCBs	Does not achieve.	Not predicted to achieve.								
	Dioxins/Furans	0 (achieves at baseline conditions or start of construction)									
Natural Background PRGs	Total PCBs	Does not achieve.	Not predicted to achieve.								
	Dioxins/Furans[c]	Does not achieve.	Not predicted to achieve.								
RAO 2 - Human Health (Direct Contact)											
Netfishing (Natural Background Based PRG for As)	Arsenic[d]	Does not achieve.	9[b]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
Tribal Clamming (Natural Background Based PRG for As)		Does not achieve.	9[b]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
RAO 3 - Ecological Health (Benthic Organisms)											
Benthic (Benthic SCOs)[e]	29 COCs	Not expected to achieve all PRGs.	39[f]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
RAO 4 - Ecological Health (Fish)											
English Sole (SWAC < PRG [370 µg/kg dw])	Total PCBs	10	9[b]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
Brown Rockfish (SWAC < PRG [250 µg/kg dw])		25	9[b]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]

Notes:

1. As described in Section 8.1.1.8, the Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15. However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15 (i.e., 100 days/season). It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15), thus, the upper end of the number of work days in a construction season could increase to around 150 days/season, decreasing the total number of years of construction by 2 years, consistently across the action alternatives. Therefore, times to achieve RAOs could be reduced, compared to those presented in this table.

a. Model-predicted concentrations and associated risks were calculated based on the effective concentration considering bioavailability (i.e., 70% reduction in concentration due to in situ treatment) for the alternatives that include in situ treatment (all alternatives except Alternative 1A(12)) for total PCBs, cPAHs, and dioxins/furans.
b. Evaluation metric is predicted to be achieved by the end of construction.

c. No alternatives are predicted to meet either the natural background concentration for dioxins/furans of 2 ng TEQ/kg dw (calculated based on the UCL95 on the mean, using the OSV Bold Survey [DMMP 2009] dataset [LDW ROD]; EPA 2014).
d. Alternatives 1A(12) through 3E(7.5) are predicted to meet natural background based PRG for arsenic of 7 mg/kg dw (calculated based on the UCL95; LDW ROD 2014) immediately after construction, and may maintain this value in the long term, depending on concentrations in Green River sediments.
e. For FS purposes, achievement of RAO 3 is based on at least 98% of predicted surface sediment locations achieving PRGs for all 29 benthic COCs. This metric acknowledges that the SMS has some flexibility in defining practicability for compliance with the SQS. In addition, the FS recognizes that, given the uncertainty in predictions of future contaminant concentrations based on model- and contaminant-specific assumptions, achievement of 100% compliance with the SQS may not prove to be practicable. Small numbers of SQS point exceedances may represent the potential for isolated minor adverse effects on the benthic community, and those do not necessarily merit further action based on a number of factors (such as sediment toxicity test results), as prescribed in the SMS. Adaptive management measures (e.g., verification monitoring, contingency actions) may become necessary, consistent with the technical feasibility provisions of the SMS, in response to isolated or localized SQS point exceedances. Predictive modeling was not conducted for the No Action Alternative for compliance with RAO 3.
f. Time to achieve RAO 3 PRG based on total PCBs; all other benthic risk driver COCs achieve PRGs immediately after construction completion.

API – Asian Pacific Islander; COC – contaminant of concern; cPAH – carcinogenic polycyclic aromatic hydrocarbon; dw – dry weight; EW – East Waterway; FS – Feasibility Study; LDW – Lower Duwamish Waterway; mg/kg – milligram per kilogram; µg/kg – microgram per kilogram; ng TEQ/kg – nanograms toxic equivalent per kilogram; PCB – polychlorinated biphenyl; PRG – preliminary remediation goal; RAO – remedial action objective; RME – reasonable maximum exposure; ROD – Record Of Decision; SCO – sediment cleanup objective; SMS – Sediment Management Standards; SQS – sediment quality standard; SWAC – spatially-weighted average concentration; TEQ – toxic equivalent; UCL95 – 95% upper confidence level on the mean

- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

The No Action Alternative includes site-wide long-term monitoring to ascertain actual concentrations achieved over time. However, the alternative does not assume any actions (e.g., contingency actions) in response to the monitoring data.

With these considerations, the No Action Alternative does not meet the threshold criterion of overall protection of human health and the environment.

9.4.2 Compliance with ARARs

The No Action Alternative does not comply with ARARs because it is not expected to achieve certain MTCA/SMS numerical cleanup standards (e.g., total PCBs and dioxins/furans for seafood consumption, based on natural background and SMS for benthic organisms) and does not include institutional controls, beyond the existing WDOH seafood consumption advisory, to manage residual risks. In addition, although surface water quality in the EW is expected to improve as a result of upland source control, it will be greatly affected by areas outside of the EW (e.g., Green River, Elliott Bay); therefore, compliance with human health surface water quality criteria for certain contaminants (e.g., total PCBs and arsenic) will not likely occur. The No Action Alternative would also not meet the MTCA requirement (WAC 173-340-440(6)) and similar CERCLA policy for primary reliance on remediation, rather than institutional controls.

9.4.3 Long-term Effectiveness and Permanence

9.4.3.1 Magnitude and Type of Residual Risk

Under the No Action Alternative, ongoing natural recovery processes are predicted to reduce risks over time, but this alternative is not expected to achieve all RAOs.

Endpoints and risk outcomes are described below for the No Action Alternative (achievement of PRGs for each RAO is discussed in Section 9.4.1):

- **RAO 1 (Tables 9-5a through 9-5d)**: The long-term (40-year) residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 4×10^{-4} (Adult Tribal RME), 8×10^{-5} (Child Tribal RME), and 2×10^{-4} (Adult API

RME). Predicted residual excess cancer risks of 7×10^{-5} (Adult Tribal RME), 1×10^{-5} (Child Tribal RME), and 3×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans. The RME seafood consumption non-cancer HQs based on the immunological, integumantary, or neurological endpoints (by year 40) associated with total PCBs are predicted to be above 1 (11 for Adult Tribal, 23 for Child Tribal, and 9 for Adult API). The RME seafood consumption non-cancer HQs based on the developmental endpoint (by year 40) associated with total PCBs are predicted to be above 1 (3 for Adult Tribal, 7 for Child Tribal, and 3 for Adult API). The seafood consumption non-cancer HQs (by year 40) associated with dioxins/furans are predicted to be equal to or below 1 for all three RME scenarios.

- **RAO 2 (Table 9-6)**: The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} (by year 40). Specifically, arsenic is predicted to result in 3×10^{-6} and 7×10^{-6} excess cancer risks by year 40 for netfishing and tribal clamming RME scenarios, respectively.
- **RAO 3 (Table 9-3):** Adverse effects to the benthic community would not be addressed because existing surface sediment locations for all key benthic risk driver COCs exceeding the PRGs will remain, although natural recovery processes may address some but not all COCs.
- **RAO 4 (Table 9-7):** In the long term (by year 40), total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and above 1.0 for both brown rockfish (HQ of 2.5) and English sole (HQ of 1.6) for the LOAEL TRV of 520 µg/kg ww.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place for the No Action Alternative, which would leave existing contaminated sediment above the RALs in place in the EW area. Of the total 146 core stations, 76 and 41 would remain containing subsurface sediment exceeding the CSL and RAL/SQS, respectively.

9.4.3.2 Adequacy and Reliability of Controls

With the exception of the continuation of the existing seafood consumption advisory and site-wide monitoring, no controls are included in this alternative. These controls would not be adequate for managing residual risks in the EW. The No Action Alternative retains the greatest amount of contaminated subsurface sediment (see Section 9.4.3.1) that could be exposed at the surface and that could be difficult to identify and manage into the future. Measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

9.4.4 Reductions in Toxicity, Mobility, or Volume through Treatment

No treatment is included in the No Action Alternative to reduce toxicity, mobility, or volume of contaminated sediments.

9.4.5 Short-term Effectiveness

9.4.5.1 Community and Worker Protection

Since the No Action Alternative assumes that no remedial actions will occur, it would not cause any additional risks due to construction activities to workers or the community beyond minor impacts during monitoring.

9.4.5.2 Environmental Impacts

Environmental impacts associated with implementation of the No Action Alternative are negligible because the only physical activity is monitoring.

9.4.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for the No Action Alternative to achieve each RAO, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2.

For RAO 1, the natural background-based PRGs for total PCBs and dioxins/furans are not achieved by the No Action Alternative within a 40-year period. The No Action Alternative is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 35 and at year 0 (baseline conditions), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME at year 0 (baseline conditions) for dioxins/furans, but does not achieve it for total PCBs

- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (baseline conditions) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (baseline conditions) for dioxins/furans, but does not achieve for total PCBs

The No Action Alternative is not predicted to achieve 7 mg/kg dw for arsenic either site-wide nor in clamming exposure areas; however, this alternative may achieve 7 mg/kg dw in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2).

For RAO 3, this alternative is not expected to achieve the PRGs because no contingency actions are included if the site does not recover through natural recovery processes (only 22% of surface sediment locations are below the PRG for all key benthic risk driver COCs at baseline [at year 0]; long-term predictions were not calculated for this alternative).

The RAO 4 PRGs for the No Action Alternative are predicted to be achieved by year 10 for English sole and by year 25 for brown rockfish.

9.4.6 Implementability

The No Action Alternative is administratively implementable. The only action undertaken is monitoring. Further, because this is the CERCLA No Action Alternative, no contingency actions are assumed to be undertaken in response to monitoring data.

9.4.7 Cost

Only site-wide monitoring costs (assumed for a 20-year period) are associated with the No Action Alternative at an estimated cost of $950,000 (see Appendix E for details).

9.4.8 State, Tribal, and Community Acceptance

The No Action Alternative is unlikely to be acceptable to the state, tribes, and community. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD following the public comment period on EPA's Proposed Plan.

9.5 Alternative 1A(12)

Table 9-9 presents a summary for Alternative 1A(12) including areas, volumes, construction timeframe, and costs.

9.5.1 Overall Protection of Human Health and the Environment

Alternative 1A(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, partial removal and ENR-nav/ENR-nav, ENR-sill (under the West Seattle Bridge and low bridges), and MNR (underpier areas and low bridges). This alternative addresses 108 acres of contaminated sediment through dredging, partial dredging and capping, partial removal and ENR-nav/ENR-nav, and ENR-sill, and has an MNR footprint of 13 acres (Table 9-9). Alternative 1A(12) has an estimated construction period of 9 years, during which the community, workers, and the environment would be affected as described in Section 9.5.5.

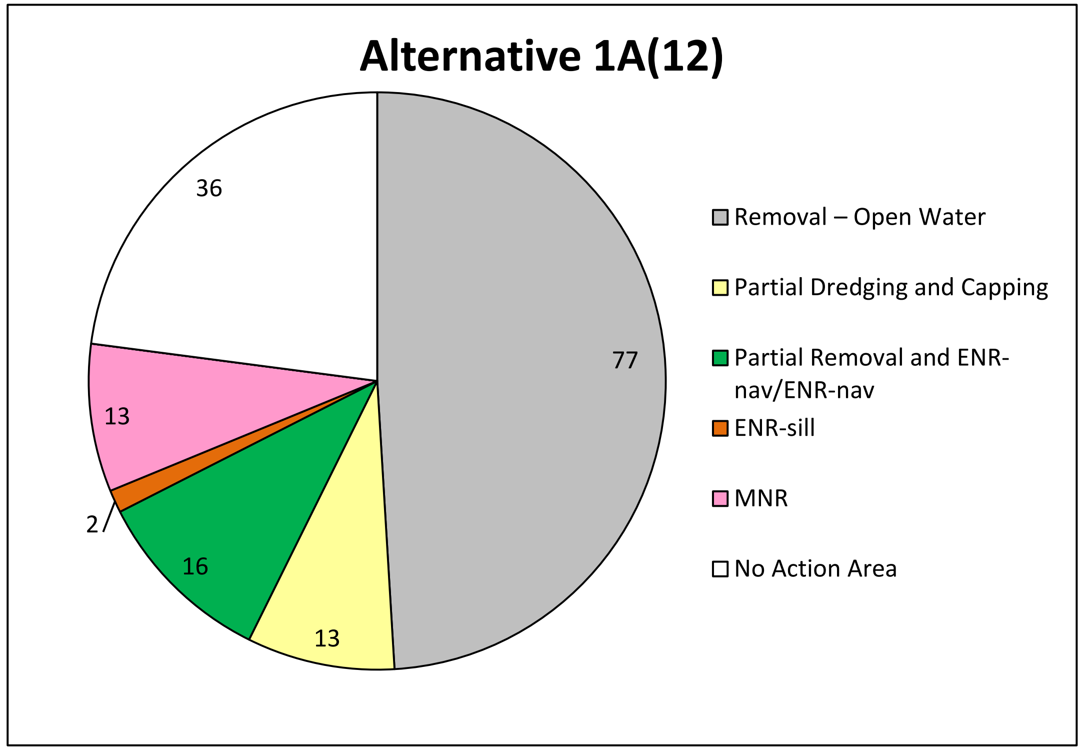
A description of PRG achievements for Alternative 1A(12) is listed below (Table 9-8):

- Alternative 1A(12) does not achieve the natural background-based PRGs for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 70% and 75% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRGs immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).
- This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk

Table 9-9
Alternative 1A(12) Summary

Areas (acres)	
Removal – Open Water	77
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	16
ENR-sill	2
MNR	13
Hydraulic Dredging Followed by In situ Treatment	0
In Situ Treatment	0
No Action Area	36
Volumes (cy)	
Total Removal Volume	810,000
Total Placement Volume	290,000
Construction Timeframe (years)	
Construction Time	9
Costs ($ Million)	
Construction Costs	196
Non-construction Costs	60
Total Costs (rounded)	256



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring and maintenance are required for this alternative, which includes 13 acres of partial dredging and capping, 16 acres of partial removal and ENR-nav/ENR-nav, 2 acres of ENR-sill, and 13 acres of MNR.

Considering the factors described in this section, Alternative 1A(12) achieves the threshold criterion of overall protection of human health and the environment.

9.5.2 Compliance with ARARs

Alternative 1A(12) is expected to comply with ARARs as follows:

- This alternative is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[116] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. For protection of human health for seafood consumption (RAO 1), modeling predicts that Alternative 1A(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW. CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:
  - Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may

[116] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long-term after construction due to incoming sediment concentrations.

take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).

  - SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

- Although surface water quality in the EW is expected to improve as a result of sediment remediation and upland source control, but it will be greatly affected by areas outside of the EW (e.g., Green River, Elliott Bay) and not likely comply with human health surface water quality standards for certain contaminants (e.g., total PCBs and arsenic).

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 1A(12) achieves the threshold criterion of compliance with ARARs.

9.5.3 Long-term Effectiveness and Permanence

9.5.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 1A(12) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to slowly decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 1A(12) (achievement of PRGs for each RAO is discussed in Section 9.5.1):

- **RAO 1 (Tables 9-5a through 9-5d):** Long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 4×10^{-5} (Child Tribal RME), and 8×10^{-5} (Adult API RME) 40 years after completion of construction. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 9×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 12 for Child Tribal, and 5 for Adult API) in the long term (40 years after completion of construction). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be above 1 (2 for Adult Tribal and 3 for Child Tribal), and equal to 1 (for Adult API) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs 40 years after completion of construction associated with dioxins/furans are predicted to be at or below 1 for all three RME scenarios.
- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[117]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs (30 years after construction completion; 39 years, including construction time) and all other key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 μg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.3 for brown rockfish for the LOAEL TRV of 520 μg/kg ww 40 years after completion of construction.

[117] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, with partial removal and ENR-nav/ENR-nav and ENR-sill areas having smaller potential than MNR areas. Based on the approach outlined in Section 9.1.2.1, Table 9-10 evaluates the post-construction potential to increase surface sediment concentrations from exposure of subsurface contamination. Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 8 and 13, respectively; no cores greater than CSL and four cores greater than RAL/SQS would remain in areas with partial removal and ENR-nav/ENR-nav; one core greater than CSL and two cores greater than RAL/SQS would remain in areas with ENR-sill; and only one core station with a concentration greater than the RAL/SQS would remain in MNR areas. The corresponding surface areas that leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 16 acres in partial removal and ENR-nav/ENR-nav, 2 acres in ENR-sill, and 13 acres in MNR areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed (Section 9.1.2.1). The majority of the sediments are being remediated through removal actions (77 acres), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.5.3.2 Adequacy and Reliability of Controls

Alternative 1A(12) removes 77 acres of contaminated sediment from the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

The 13 acres of MNR, 16 acres of partial removal and ENR-nav/ENR-nav, and 2 acres of ENR-sill under Alternative 1A(12) will require higher level of monitoring, and may require contingency actions (Table 9-9). MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill are potentially less reliable technologies than others (i.e., dredging, capping), because

Table 9-10
Post-construction Subsurface Conditions for All Alternatives

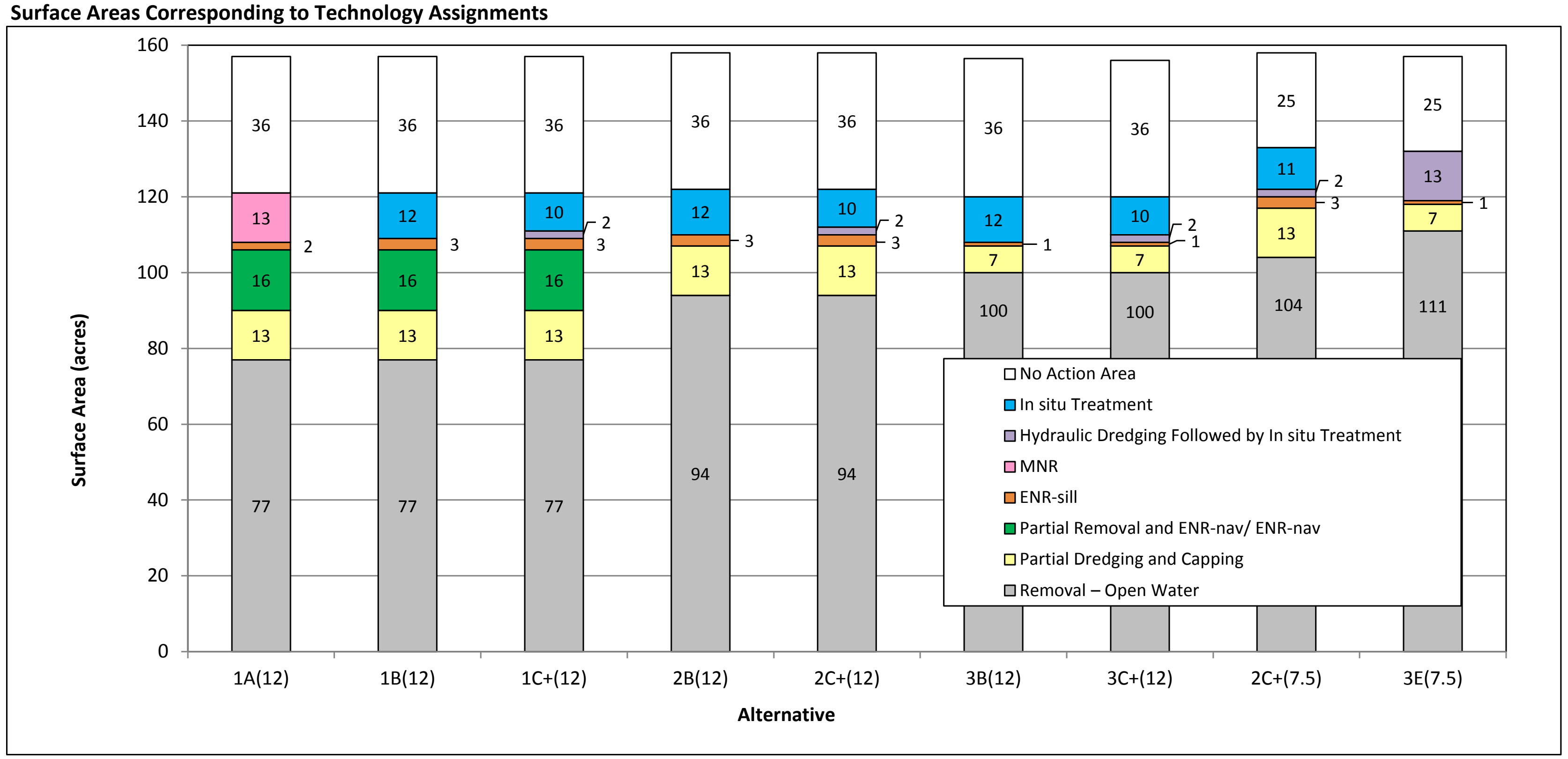
Number of Core Stations Remaining with RAL or Benthic SMS Exceedances

	Core Station Counts Remaining of Total Cores Prior to Remediation														
	Removal	Partial Dredging and Capping		Partial Removal and ENR-nav/ENR-nav		ENR-sill		MNR		Hydraulic Dredging Followed by In situ		In situ Treatment		No Action	
Alternative	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS
1A(12)	0 of 88	8 of 31	13 of 31	0 of 8	4 of 8	1 of 2	2 of 2	0 of 1	1 of 1	not used	not used	not used	not used	2 of 16	8 of 16
1B(12)	0 of 88	8 of 31	13 of 31	0 of 8	4 of 8	1 of 2	2 of 2	not used	not used	not used	not used	0 of 1	1 of 1	2 of 16	8 of 16
1C+(12)	0 of 88	8 of 31	13 of 31	0 of 8	4 of 8	1 of 2	2 of 2	not used	not used	0 of 0	0 of 0	0 of 1	1 of 1	2 of 16	8 of 16
2B(12)	0 of 96	8 of 31	13 of 31	not used	not used	1 of 2	2 of 2	not used	not used	not used	not used	0 of 1	1 of 1	2 of 16	8 of 16
2C+(12)	0 of 96	8 of 31	13 of 31	not used	not used	1 of 2	2 of 2	not used	not used	0 of 0	0 of 0	0 of 1	1 of 1	2 of 16	8 of 16
3B(12)	0 of 110	5 of 19	7 of 19	not used	not used	0 of 0	0 of 0	not used	not used	not used	not used	0 of 1	1 of 1	2 of 16	8 of 16
3C+(12)	0 of 110	5 of 19	7 of 19	not used	not used	0 of 0	0 of 0	not used	not used	0 of 0	0 of 0	0 of 1	1 of 1	2 of 16	8 of 16
2C+(7.5)	0 of 98	8 of 31	13 of 31	not used	not used	1 of 2	2 of 2	not used	not used	0 of 0	0 of 0	0 of 1	1 of 1	2 of 14	8 of 14
3E(7.5)	0 of 112	5 of 19	7 of 19	not used	not used	0 of 0	0 of 0	not used	not used	0 of 1	0 of 1	not used	not used	2 of 14	8 of 14

Notes:

1. The total number of core stations is 146; 1 in the underpier areas and 145 in open-water areas.
2. RAL or benthic SMS exceedances are assumed to be the maximum exceedance within the total core depth interval.
3. For the No Action Alternative, of the 146 total core stations, 76 and 41 remain containing subsurface sediment exceeding the CSL and RAL/SQS, respectively.
4. When no core stations were available within a footprint where a specific remedial technology is applied, "0 of 0 cores" was noted.

Surface Areas Corresponding to Technology Assignments



Notes:

1. The total East Waterway Operable Unit surface area is 157 acres.
2. Removal – Open Water includes removal to extent practicable and backfill (Communications Cable Crossing Area) and removal and backfill to existing contours.
3. ENR-nav is enhanced natural recovery applied in the navigation channel and deep-draft berthing areas. It includes partial dredging/ENR-nav and ENR-nav.
4. ENR-sill is enhanced natural recovery applied in the Sill Reach.
5. Two dredge material characterization cores that represent the upper 4-feet of sediment contained concentrations above CSL in the no action area. These areas will be confirmed during remedial design to determine if concentrations are above RALs in surface and shallow subsurface sediment.

CSL – cleanup screening level; ENR – enhanced natural recovery; MNR – monitored natural recovery; n – number of cores; not used – technology not used for the alternative; RAL – remedial action level; SMS – Sediment Management Standards; SQS – sediment quality standard sedimentation rates and contaminant input concentrations are uncertain components of natural recovery. The amount of mixing of open-water sediments with underpier sediments (e.g., sediment exchange) is also a factor that affects natural recovery. Mechanisms such as propeller scour and earthquakes can also more easily expose buried contaminated sediment in MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas. If, as a result of long-term monitoring, MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas indicate unacceptable performance, contingency actions are assumed to be necessary and are included in the cost estimate (see Appendix E). Alternative 1A(12) leaves little contaminated subsurface sediment that could be redistributed in place in MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas (see Section 9.5.3.1 and Table 9-10). While the box model assumes a certain level of exchange of underpier sediment to open-water areas, redistribution or exposure of contaminated sediment in MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 1A(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place in areas remediated with caps, partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR (Section 9.5.3.1). To prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment, the Institutional Controls Plan will include the following, at a minimum:

- Seafood consumption advisories and public outreach and education programs
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users
- Designation of RNAs and other forms of notification and controls for areas with residual contamination to ensure the performance of the remedy

The public outreach and education components are intended to enhance the reliability of the seafood consumption advisories. The advisories themselves are not enforceable and, therefore, have limited reliability.

The combination of monitoring, maintenance, and institutional controls, 5-year reviews as required under CERCLA, and contingency actions (if required), are intended to enhance remedy integrity. As a whole, these activities are intended to allow Alternative 1A(12) to be adaptively managed, as needed, based on new information.

9.5.4 Reductions in Toxicity, Mobility, or Volume through Treatment

No treatment is included in Alternative 1A(12) to reduce toxicity, mobility, or volume of contaminated sediments.

9.5.5 Short-term Effectiveness

9.5.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 9-year construction period for Alternative 1A(12). Fish and shellfish tissue concentrations are predicted to remain elevated throughout the construction period and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (72,400, 125,900, and 12,500, respectively) estimated to support material hauling operations, both for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, partial removal and ENR-nav/ENR-nav, ENR-sill, backfilling of dredged areas, and RMC (see Appendix I).

Work-related accidents may occur during construction and are proportional to volume of material handled, transportation, and the duration of the remediation activities of Alternative 1A(12) (see Appendix I).

9.5.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations (and also occurs to a lesser degree via man-made erosion events [e.g., propwash scour]). For Alternative 1A(12), it would occur over nine construction seasons. Resuspension of contaminated sediments from dredging will be reduced through the use of BMPs (see Section 7.5.3). Release of contaminated sediment that settles back onto the dredged surface or onto areas just outside the dredge footprint (i.e., dredge residuals) results in concentrations above the RAL. These releases are assumed to be managed through the placement of an RMC layer (9 inches thick, with the goal of achieving a minimum thickness of 6 inches over the area dredged for Alternative 1A(12) [77 acres] and over the interior unremediated areas [19 acres]).[118]

For Alternative 1A(12), the benthic community within approximately 4.1 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010; King County 2010).

This alternative consumes regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 290,000 cy of imported granular material would be used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-9). The landfill capacity consumed by Alternative 1A(12) is proportional to the volume of dredged material removed and disposed of in the landfill (970,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal energy consumed from diesel fuel combustion during the remediation activities of Alternative 1A(12) is estimated to be 1.1×10^8 megajoules (MJ; see Appendix I).

[118] RMC is typically used as a contingency action if post-remediation surface sediment concentrations exceed a set threshold; the need, extent, and thickness of the RMC would be determined following post-removal sampling (Section 7.2.6.5).

Estimates of direct and indirect air pollutant emissions associated with Alternative 1A(12) are presented in Appendix I. Implementation of this alternative would result in approximately 16,000 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 5.4 and 5.3 metric tons, respectively), CO (64 metric tons), HCs (19 metric tons), VOCs (20 metric tons), NO_x (130 metric tons), and SO_2 (0.25 metric tons). These emissions are primarily the result of removal, transloading, and transportation of dredged contaminated sediment to the landfill and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees) is approximately 3,784 acres-year (Appendix I).

9.5.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 1A(12) to achieve each RAO, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.

For RAO 1, the natural background-based PRGs for total PCBs and dioxins/furans are not achieved by Alternative 1A(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the net incoming sediment concentration (Section 9.15.1.2). Alternative 1A(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 9 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 34 and at year 0 (start of construction), respectively

- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 1A(12) is predicted to achieve 7 mg/kg dw for arsenic by year 9 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2).

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs by 39 years for total PCBs and by 9 years (immediately after construction completion) for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 9).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.5.6 Implementability

Alternative 1A(12) has a construction period of 9 years, remediates 121 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A total of 31 acres would be remediated through the use of MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill in Alternative 1A(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas) are assumed as a contingency for Alternative 1A(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.5.7 Cost

The total cost for Alternative 1A(12) is $256 million, which includes estimated construction and non-construction costs of $196 and $60 million, respectively, and accounts for costs for contingency, management, monitoring, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.5.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.6 Alternative 1B(12)

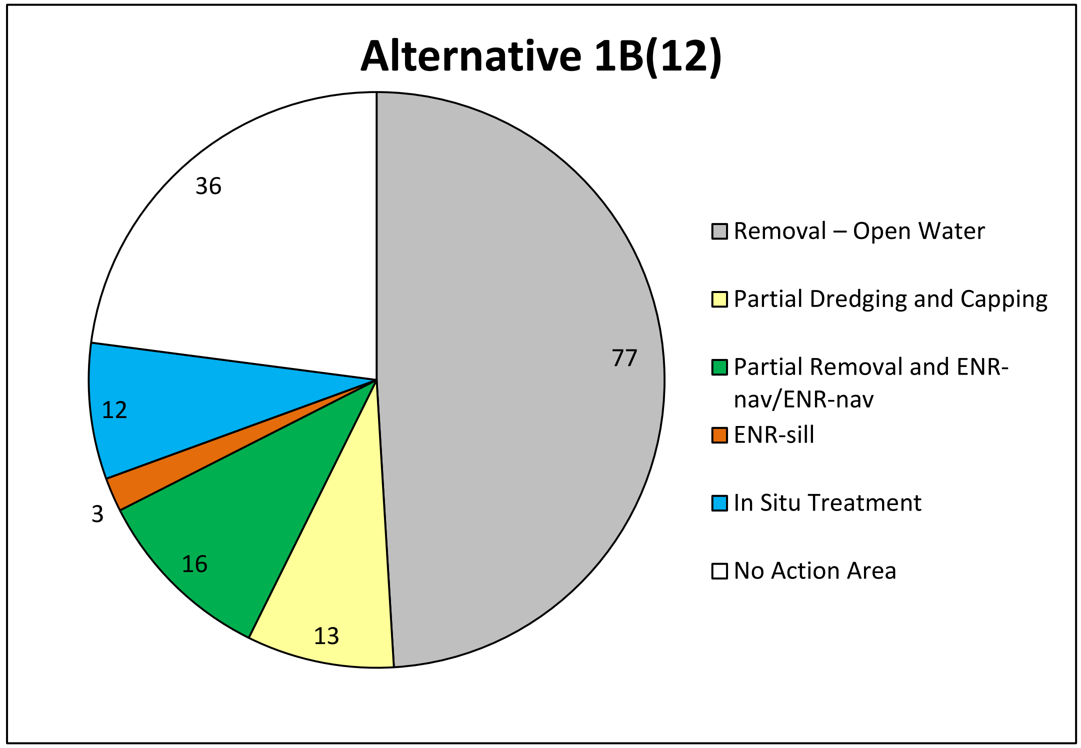
Table 9-11 presents a summary for Alternative 1B(12) including areas, volumes, construction timeframe, and costs.

9.6.1 Overall Protection of Human Health and the Environment

Alternative 1B(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, partial removal and ENR-nav/ENR-nav (in the navigation channel), ENR-sill (under the West Seattle Bridge and low bridges), and in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-11). Alternative 1B(12) has an estimated construction period of 9 years, during which the community, workers, and the environment would be affected as described in Section 9.6.5.

Table 9-11
Alternative 1B(12) Summary

Areas (acres)	
Removal – Open Water	77
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	16
ENR-sill	3
MNR	0
Hydraulic Dredging Followed by In situ Treatment	0
In Situ Treatment	12
No Action Area	36
Volumes (cy)	
Total Removal Volume	810,000
Total Placement Volume	290,000
Construction Timeframe (years)	
Construction Time	9
Costs ($ Million)	
Construction Costs	202
Non-construction Costs	62
Total Costs (rounded)	264



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

A description of PRG achievements for Alternative 1B(12) is listed below (Table 9-8):

- Alternative 1B(12) does not achieve the natural background-based PRGs for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).
- This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 13 acres of partial dredging and capping, 16 acres of partial removal and ENR-nav/ENR-nav, 3 acres of ENR-sill, and 12 acres of in situ treatment.

Considering the factors described in this section, Alternative 1B(12) achieves the threshold criterion of overall protection of human health and the environment.

9.6.2 Compliance with ARARs

Alternative 1B(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[119] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 1B(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

[119] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction, due to incoming sediment concentrations.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 1B(12) achieves the threshold criterion of compliance with ARARs.

9.6.3 Long-term Effectiveness and Permanence

9.6.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 1B(12) significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 1B(12) (achievement of PRGs for each RAO is discussed in Section 9.6.1):

- **RAO 1 (Tables 9-5a through 9-5d):** Long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins and furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs (40 years after construction completion) associated with dioxins/furans are predicted to be below 1 for all three RME scenarios.

- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[120]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within the partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas. Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 8 and 13, respectively; no cores greater than CSL and four cores greater than RAL/SQS would remain in areas with partial removal and ENR-nav/ENR-nav; one greater than CSL and two greater than RAL/SQS would remain in areas with ENR-sill; and only one core station with a concentration greater than the RAL/SQS would remain in in situ treatment areas. The corresponding surface areas that leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 16 acres in partial removal and ENR-nav/ENR-nav, 3 acres in ENR-sill, and 12 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (77 acres), which results in a much smaller percentage of the waterway with residual contamination left in place.

[120] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

9.6.3.2 Adequacy and Reliability of Controls

Alternative 1B(12) removes 77 acres of contaminated sediment from the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

The 16 acres of partial removal and ENR-nav/ENR-nav, 3 acres of ENR-sill, and 12 acres of in situ treatment under Alternative 1B(12) will require a higher level of monitoring, and may require contingency actions (Table 9-11). As described for Alternative 1A(12), partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment are potentially less reliable technologies than others (i.e., dredging, capping), because: a) sedimentation rates and contaminant input concentrations are uncertain components of natural recovery; and b) other mechanisms can expose buried contaminated sediment in ENR and in situ treatment areas. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates these areas have unacceptable performance (see Section 9.5.3.2). Alternative 1B(12) leaves contaminated subsurface sediment in place in partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas (see Section 9.6.3.1 and Table 9-10), which could be exposed at the sediment surface or, in the case of in situ treatment areas, be redistributed from underpier areas to open-water areas. While the box model predicts a certain level of exchange of underpier sediment to open-water areas, redistribution or exposure of contaminated sediment in partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 1B(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place (Section 9.6.3.1). The Institutional Controls Plan will include, at a minimum, the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls, 5-year reviews as required under CERCLA, and contingency actions (if required), are intended to enhance remedy integrity and to allow Alternative 1B(12) to be adaptively managed, as needed, based on new information.

9.6.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-11).

9.6.5 Short-term Effectiveness

9.6.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 9-year construction period for Alternative 1B(12). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (76,000, 126,200, and 12,500, respectively) estimated to support material hauling operations, both for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, partial removal and ENR-nav/ENR-nav, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, transportation, and duration of the remediation activities of Alternative 1B(12) see Appendix I).

9.6.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations, which for Alternative 1B(12) would occur over nine construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 1B(12) (77 acres) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 1B(12), the benthic community within approximately 4.1 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010; King County 2010).

This alternative consumes regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 290,000 cy of imported granular material would be used for capping, partial removal and ENR-nav/ENR-nav, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-11). The landfill capacity consumed by Alternative 1B(12) is proportional to the volume of dredged material removed and disposed of in the landfill (970,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal energy consumed from diesel fuel combustion during the remediation activities of Alternative 1B(12) is estimated to be 1.1×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 1B(12) are presented in Appendix I. Implementation of this alternative would result in approximately 16,000 tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 5.6 and 5.5 metric tons, respectively), CO (67 metric tons), HCs and VOCs (20 and 21 metric tons, respectively), NO_x (140 metric tons), and SO_2 (0.26 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 3,784 acre-years (Appendix I).

9.6.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 1B(12) to achieve each RAO, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[121]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 1B(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 1B(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 9 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 9 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 1B(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 9 (immediately after construction completion) for both site-wide and clamming exposure areas, and may

[121] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

achieve 7 mg/kg dw in the long term, depending on net incoming sediment concentration (Section 9.15.1.2).

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs by year 9 (immediately after construction completion) for total PCBs and the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 9).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.6.6 Implementability

Alternative 1B(12) has a construction period of 9 years, remediates 121 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-11). Access to the sediments would be difficult due to the presence of the supporting piles and the low overhead clearance under the pier deck surfaces. As discussed in Section 7.2.7.1, the use of traditional marine-based dredging or barge-mounted placement equipment is precluded due to these access restrictions. The primary in situ treatment technology considered for use in the EW is placement of activated carbon, which is required to be handled as bulk material from a stockpile and placed at a specified amount per surface area on the sediments to be treated. Methods for moving this material into confined places (such as the underpier areas) may be limited to specialized equipment and placement methods (e.g., long-reach conveyors such as

Telebelt™ or hydraulic/pneumatic pumping and placement), but these techniques are expected to be implementable.

A total of 31 acres would be remediated through the use of partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment in Alternative 1B(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas) are assumed as a contingency for Alternative 1B(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.6.7 Cost

The total cost for Alternative 1B(12) is $264 million, which includes estimated construction and non-construction costs of $202 and $62 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.6.8 State, Tribal, and Community Acceptance

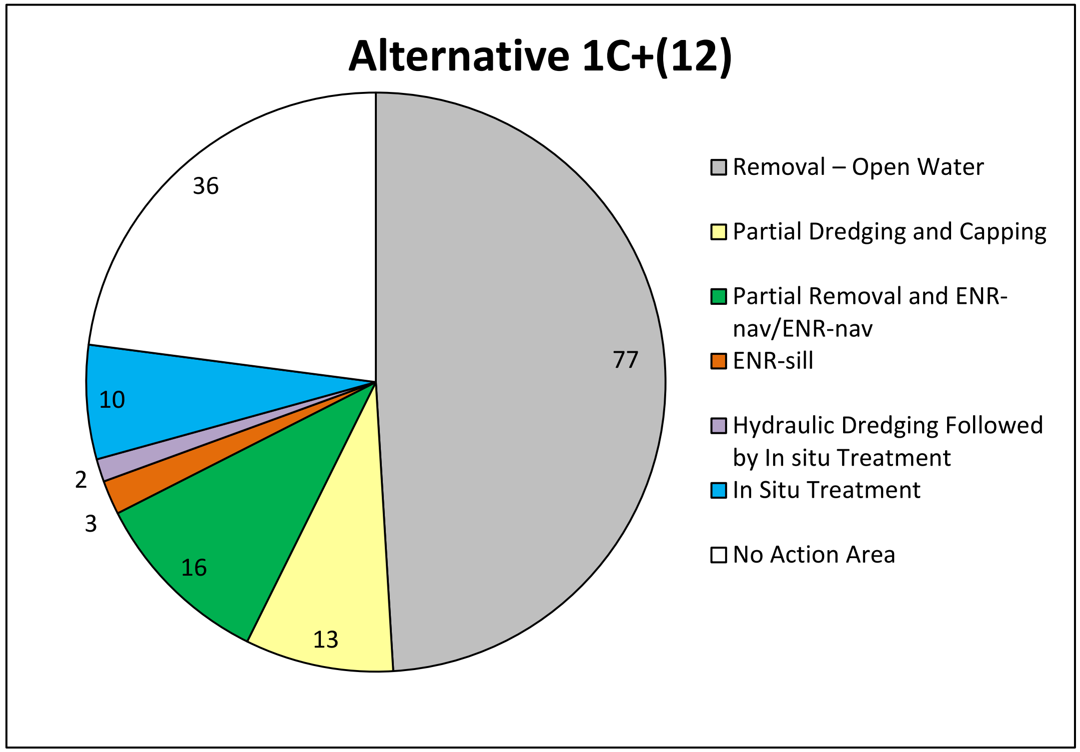
See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.7 Alternative 1C+(12)

Table 9-12 presents a summary for Alternative 1C+(12) including areas, volumes, construction timeframe, and costs.

Table 9-12
Alternative 1C+(12) Summary

Areas (acres)	
Removal – Open Water	77
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	16
ENR-sill	3
MNR	0
Hydraulic Dredging Followed by In situ Treatment	2
In Situ Treatment	10
No Action Area	36
Volumes (cy)	
Total Removal Volume	820,000
Total Placement Volume	290,000
Construction Timeframe (years)	
Construction Time	9
Costs ($ Million)	
Construction Costs	214
Non-construction Costs	63
Total Costs (rounded)	277



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

9.7.1 Overall Protection of Human Health and the Environment

Alternative 1C+(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, partial removal and ENR-nav/ENR-nav (under navigation channel), ENR-sill (under West Seattle Bridge and low bridges), and in situ treatment and diver-assisted hydraulic dredging followed by in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-12). Alternative 1C+(12) has an estimated construction period of 9 years, during which the community, workers, and the environment would be affected as described in Section 9.7.5.

A description of PRG achievements for Alternative 1C+(12) is listed below (Table 9-8):

- Alternative 1C+(12) does not achieve the natural background-based PRGs for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2). This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 13 acres of partial dredging and capping, 16 acres of partial removal and ENR-nav/ENR-nav, 3 acres of ENR-sill, 10 acres of in situ treatment, and 2 acres of diver-assisted hydraulic dredging followed by in situ treatment.

Considering the factors described in this section, Alternative 1C+(12) achieves the threshold criterion of overall protection of human health and the environment.

9.7.2 Compliance with ARARs

Alternative 1C+(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[122] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts thatAlternative 1C+(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).

[122] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction, due to incoming sediment concentrations.

- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, Alternative 1C+(12) will not likely comply with human health surface WQS for total PCBs and arsenic.
A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 1C+(12) achieves the threshold criterion of compliance with ARARs.

9.7.3 Long-term Effectiveness and Permanence

9.7.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 1C+(12) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 1C+(12) (achievement of PRGs for each RAO is discussed in Section 9.7.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 9×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API

RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be at or below 1 for all three RME scenarios (40 years after construction completion).

- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[123]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas. Table 9-10 shows that the numbers of core stations with CSL and RAL/SQS exceedances remaining in areas that are partially removed and capped are 8 and 13, respectively; no cores greater than CSL and four cores greater than RAL/SQS would remain in areas with partial removal and ENR-nav/ENR-nav; one greater

[123] Arsenic natural background concentrations exceed 1 x 10^{-6} excess cancer threshold (see Section 9.3.3.2).

than CSL and two greater than RAL/SQS would remain in areas with ENR-sill; and only one core station with a concentration greater than the RAL/SQS would remain in in situ treatment areas. The corresponding surface areas that leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 16 acres in partial removal and ENR-nav/ENR-nav, 3 acres in ENR-sill, and 10 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (79 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.7.3.2 Adequacy and Reliability of Controls

Alternative 1C+(12) removes 79 acres of contaminated sediment from the EW (including 2 acres with diver-assisted hydraulic dredging in underpier areas) and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals left behind by diver-assisted hydraulic dredging. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

The 16 acres of partial removal and ENR-nav/ENR-nav, 3 acres of ENR-sill, and 12 acres of in situ treatment under Alternative 1C+(12) will require a higher level of monitoring and may require contingency actions (Table 9-12). As described for Alternative 1A(12), partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment are potentially less reliable as technologies than others (i.e., dredging, capping), because: a) sedimentation rates and contaminant input concentrations are uncertain components of natural recovery; and b) other mechanisms that can easily expose buried contaminated sediment in partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates these areas have unacceptable performance (see Section 9.5.3.2). Alternative 1C+(12) leaves contaminated subsurface sediment in place in partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas (see Section 9.7.3.1 and Table 9-10), which could be exposed at the sediment surface or be redistributed from underpier areas to open-water areas. While the box model predicts a certain level of exchange of underpier sediment (including residuals left behind by diver-assisted hydraulic dredging) to open-water areas, redistribution or exposure of contaminated sediment in these areas has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 1C+(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds because (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place (Section 9.7.3.1). The Institutional Controls Plan will include, at a minimum, the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 1C+(12) to be adaptively managed, as needed, based on new information.

9.7.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-12).

9.7.5 Short-term Effectiveness

9.7.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 9-year construction period for Alternative 1C+(12). Fish and shellfish tissue concentrations are predicted to remain elevated for during construction and sometime thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (76,600, 126,200, and 12,600, respectively) estimated to support material hauling operations, both for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, partial removal and ENR-nav/ENR-nav, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, amount of diver-assisted hydraulic dredging, transportation, and duration of the remediation activities of Alternative 1C+(12) (see Appendix I). This alternative includes 2 acres of diver-assisted hydraulic dredging in underpier locations over two construction seasons, which has intrinsic high safety concerns, especially in deeper water and under structures.

9.7.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations, which for Alternative 1C+(12) would occur over nine construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 1C+(12) (79 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 1C+(12), the benthic community within approximately 4.1 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative consumes regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 290,000 cy of imported granular material would be used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-12). The landfill capacity consumed by Alternative 1C+(12) is proportional to the volume of dredged material removed and disposed of in the landfill (980,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal energy consumed (from diesel fuel combustion and water treatment due to diver-assisted hydraulic dredging, respectively) during the remediation activities of Alternative 3 is estimated to be 1.2×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 1C+(12) are presented in Appendix I. Implementation of this alternative would result in approximately 16,100 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 5.9 and 5.8 metric tons, respectively), CO (73 metric tons), HCs (22 metric tons), VOCs (23 metric tons), NO_x (140 metric tons), and SO_2 (0.27 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 3,808 acres-year (Appendix I).

9.7.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 1C+(12) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[124]

[124] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 1C+(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 1C+(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 9 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 9 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 1C+(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 9 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs by year 9 (immediately after construction completion) for total PCBs for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 9).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.7.6 Implementability

Alternative 1C+(12) has a construction period of 9 years, remediates 121 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-12). Anticipated access restrictions and placement methods of activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

Alternative 1C+(12) also includes removal (2 acres; Table 9-12) in underpier areas, followed by in situ treatment. Removing contaminated sediment from underpier locations presents significant engineering and construction difficulties. Diver-assisted hydraulic dredging has the same considerations as standard hydraulic dredging, but with significant additional technical issues and safety concerns, including extremely low production rates, need to treat and manage large volumes of water from sediment slurry, inability to remove consolidated sediment, inability to remove debris, and risk for injury or death. Factors affecting the feasibility of underpier dredging are listed in Sections 7.2.6.3 and 9.1.2.4.

A total of 31 acres would be remediated through the use of partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment in Alternative 1C+(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas) are assumed as a contingency for Alternative 1C+(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.7.7 Cost

The total cost for Alternative 1C+(12) is $277 million, which includes estimated construction and non-construction costs of $214 and $63 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.7.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.8 Alternative 2B(12)

Table 9-13 presents a summary for Alternative 2B(12) including areas, volumes, construction timeframe, and costs.

9.8.1 Overall Protection of Human Health and the Environment

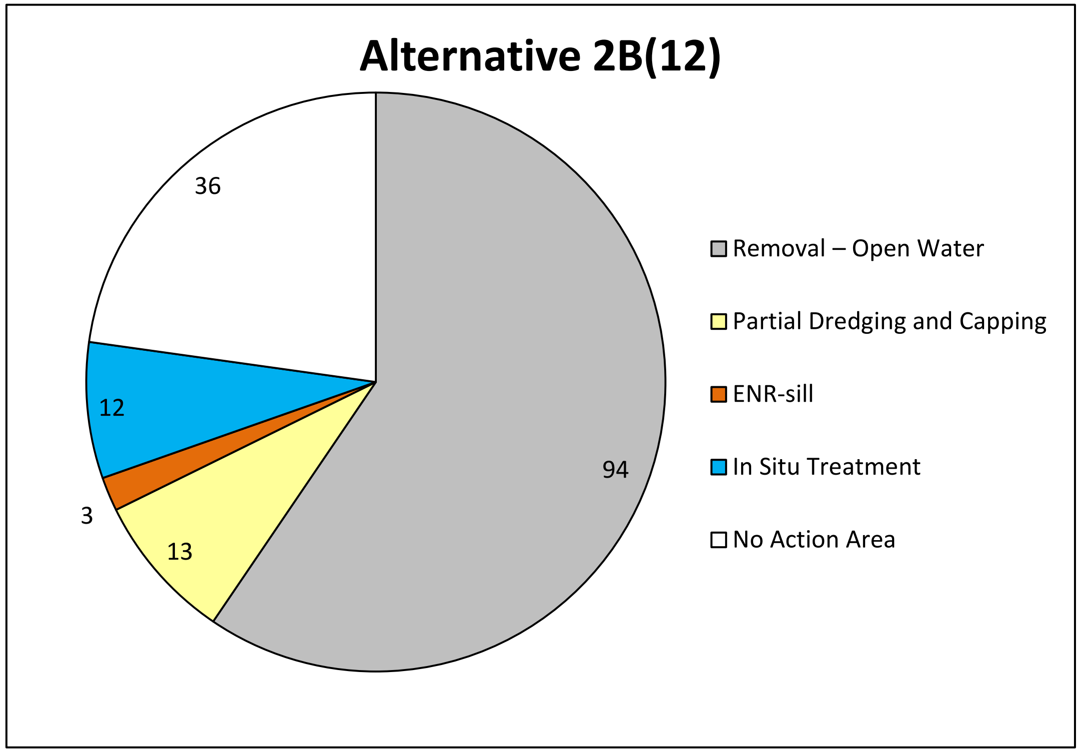
Alternative 2B(12) emphasizes removal and upland disposal followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under the West Seattle Bridge and under low bridges), and in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-13). Alternative 2B(12) has an estimated construction period of 10 years, during which the community, workers, and the environment would be affected as described in Section 9.8.5.

A description of PRG achievements for Alternative 2B(12) is listed below (Table 9-8):

- Alternative 2B(12) does not achieve the natural background-based PRGs for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).

Table 9-13
Alternative 2B(12) Summary

Areas (acres)	
Removal – Open Water	94
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	3
MNR	0
Hydraulic Dredging Followed by In situ Treatment	0
In Situ Treatment	12
No Action Area	36
Volumes (cy)	
Total Removal Volume	900,000
Total Placement Volume	280,000
Construction Timeframe (years)	
Construction Time	10
Costs ($ Million)	
Construction Costs	221
Non-construction Costs	63
Total Costs (rounded)	284



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2). This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 13 acres of partial dredging and capping, 12 acres of in situ treatment, and 3 acres of ENR-sill.

Considering the factors described in this section, Alternative 2B(12) achieves the threshold criterion of overall protection of human health and the environment.

9.8.2 Compliance with ARARs

Alternative 2B(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[125] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling

[125] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

predicts that Alternative 2B(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, EPA may issue a ROD Amendment or ESD providing the basis for a TI or other waiver for specified ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 2B(12) achieves the threshold criterion of compliance with ARARs.

9.8.3 Long-term Effectiveness and Permanence

9.8.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 2B(12) significantly would reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 2B(12) (achievement of PRGs for each RAO is discussed in Section 9.8.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).
- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[126]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the

[126] Arsenic natural background concentrations exceed 1 x 10^{-6} excess cancer threshold (see Section 9.3.3.2).

PRGs for total PCBs and all key benthic risk driver COCs (immediately after construction completion).

- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas. Table 9-10 shows that the numbers of core stations that would have remaining CSL and RAL/SQS exceedances in areas that are partially removed and capped are 8 and 13, respectively; one core greater than CSL and two cores greater than RAL/SQS would remain in areas with ENR-sill; and one core greater than RAL/SQS would remain in areas with in situ treatment. The corresponding surface areas that would leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 3 acres in ENR-sill, and 12 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (94 acres), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.8.3.2 Adequacy and Reliability of Controls

Alternative 2B(12) removes 94 acres of contaminated sediment from the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

Only 3 acres of ENR-sill, and 12 acres of in situ treatment (in underpier areas) under Alternative 2B(12) will require a higher level of monitoring and may require contingency actions (Table 9-13). As described for Alternative 1A(12), ENR-sill and in situ treatment are potentially less reliable technologies than others (i.e., dredging, capping) because: a) sedimentation rates and contaminant input concentrations are uncertain components of natural recovery; and b) other mechanisms that can easily expose buried contaminated sediment in ENR and in situ treatment areas. Some uncertainty is also associated with actual reductions in bioavailability as a result of in situ treatment, along with the potential for higher propwash events to redistribute some of the in situ treatment material. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates ENR-sill or in situ treatment areas have unacceptable performance (see Section 9.5.3.2). Alternative 2B(12) leaves contaminated subsurface sediment in place within in situ treatment and ENR-sill areas (see Section 9.8.3.1 and Table 9-10). Therefore, some level of exposure of the sediment surface or redistribution from underpier areas to open-water areas is anticipated affecting long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 2B(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs remains in place (Section 9.8.3.1). The Institutional Controls Plan will include at a minimum the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 2B(12) to be adaptively managed, as needed, based on new information.

9.8.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-13).

9.8.5 Short-term Effectiveness

9.8.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 10-year construction period for Alternative 2B(12). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.
Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (83,900, 121,600, and 12,800, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, transportation, and duration of the remediation activities of Alternative 2B(12) (see Appendix I).

9.8.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment expected to occur to some degree during dredging operations, which for Alternative 2B(12) would occur over ten construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 2B(12) (94 acres) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 2B(12), the benthic community within approximately 4.1 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative consumes regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 280,000 cy of imported granular material would be used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-13). The landfill capacity consumed by Alternative 2B(12) is proportional to the volume of dredged material removed and disposed of in the landfill (1,080,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal energy consumed from diesel fuel combustion during the remediation activities of Alternative 4 is estimated to be 1.2×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 2B(12) are presented in Appendix I. Implementation of this alternative would result in approximately 17,000 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 6.1 and 6.0 metric tons, respectively), CO (72 metric tons), HCs (22 metric tons), VOCs (23 metric tons), NO_x (150 metric tons), and SO_2 (0.27 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 4,021 acres-year (Appendix I).

9.8.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 2B(12) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[127]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 2B(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 2B(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 2B(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 10 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 10) for total PCBs and for the other key benthic risk driver COCs.

[127] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 10).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.8.6 Implementability

Alternative 2B(12) has a construction period of 10 years, remediates 121 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-13). Anticipated access restrictions and placement methods of activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

A total of 15 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 2B(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment would require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed to be likely for Alternative 2B(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.8.7 Cost

The total cost for Alternative 2B(12) is $284 million, which includes estimated construction and non-construction costs of $221 and $63 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.8.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.9 Alternative 2C+(12)

Table 9-14 presents a summary for Alternative 2C+(12) including areas, volumes, construction timeframe, and costs.

9.9.1 Overall Protection of Human Health and the Environment

Alternative 2C+(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under West Seattle Bridge and low bridges), and in situ treatment and diver-assisted hydraulic dredging followed by in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-14).

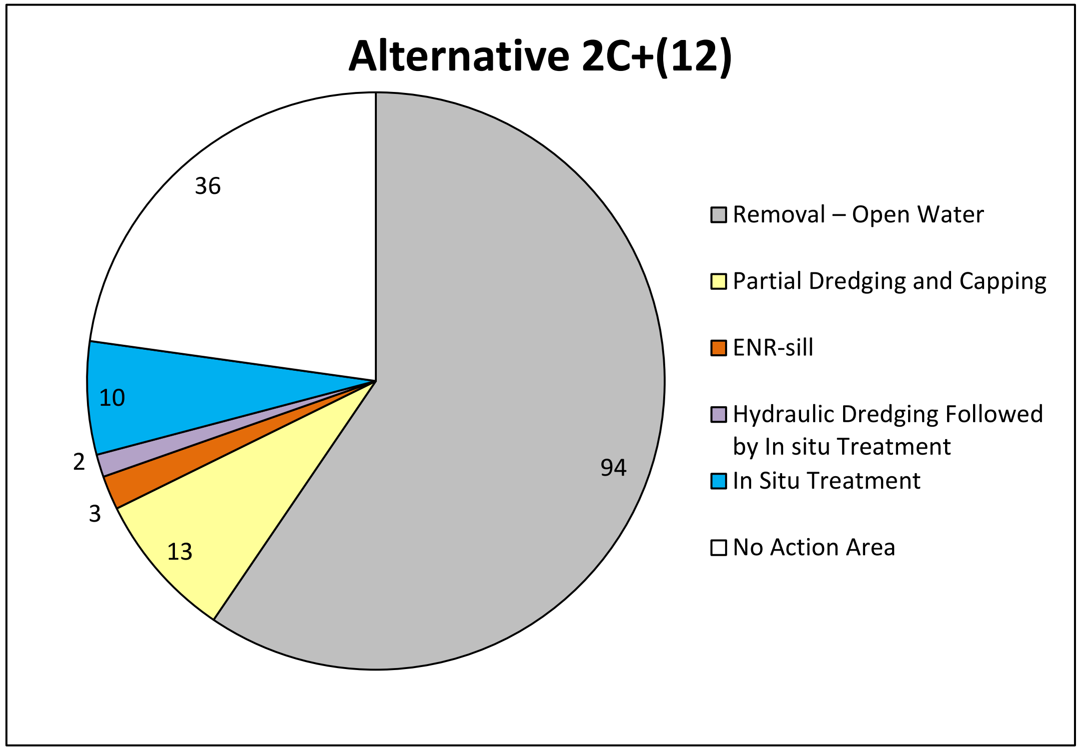
Alternative 2C+(12) has an estimated construction period of 10 years, during which the community, workers, and the environment would be affected as described in Section 9.9.5.

A description of PRG achievements for Alternative 2C+(12) is listed below (Table 9-8):

- Alternative 2C+(12) does not achieve the natural background-based PRG for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).

Table 9-14
Alternative 2C+(12) Summary

Areas (acres)	
Removal – Open Water	94
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	3
MNR	0
Hydraulic Dredging Followed by In situ Treatment	2
In Situ Treatment	10
No Action Area	36
Volumes (cy)	
Total Removal Volume	910,000
Total Placement Volume	280,000
Construction Timeframe (years)	
Construction Time	10
Costs ($ Million)	
Construction Costs	233
Non-construction Costs	64
Total Costs (rounded)	297



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2). This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentration. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 13 acres of partial dredging and capping, 3 acres of ENR-sill, 2 acres of diver-assisted hydraulic dredging followed by in situ treatment, and 10 acres of in situ treatment.

Considering the factors described in this section, Alternative 2C+(12) achieves the threshold criterion of overall protection of human health and the environment.

9.9.2 Compliance with ARARs

Alternative 2C+(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[128] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health

[128] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 2C+(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 2C+(12) achieves the threshold criterion of compliance with ARARs.

9.9.3 Long-term Effectiveness and Permanence

9.9.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 2C+(12) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 2C+(12) (achievement of PRGs for each RAO is discussed in Section 9.9.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).
- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[129]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface subsurface sediment locations are predicted to be

[129] Arsenic natural background concentrations exceed 1 x 10^{-6} excess cancer threshold (see Section 9.3.3.2).

below the PRGs for total PCBs and all other key benthic risk driver COCs (immediately after construction completion).

- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within ENR-sill and in situ treatment areas). Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 8 and 13, respectively; one core greater than CSL and two cores greater than RAL/SQS would remain in areas with ENR-sill; and one core greater than RAL/SQS would remain in areas with in situ treatment areas. The corresponding surface areas that leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 3 acres in ENR-sill, and 10 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (96 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.9.3.2 Adequacy and Reliability of Controls

Alternative 2C+(12) removes 96 acres (including 2 acres with diver-assisted hydraulic dredging in underpier areas) of contaminated sediment from the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals left behind by diver-assisted hydraulic dredging. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

The 3 acres of ENR-sill and 12 acres of in situ treatment (in underpier areas) under Alternative 2C+(12) will require more monitoring and may require contingency actions (Table 9-14). As described for Alternative 1A(12), ENR-sill and in situ treatment are potentially less reliable technologies than others (i.e., dredging, capping) because: a) sedimentation rates and contaminant input concentrations are uncertain components of natural recovery; and b) other mechanisms that can expose buried contaminated sediment in ENR-sill and in situ treatment areas. Some uncertainty is also associated with actual reductions in bioavailability as a result of in situ treatment, along with the potential for higher propwash events to redistribute some of the in situ treatment material. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates ENR-sill and in situ treatment areas have unacceptable performance (see Section 9.5.3.2). Alternative 2C+(12) leaves contaminated subsurface sediment in place in in situ treatment areas and in ENR-sill areas (see Section 9.9.3.1 and Table 9-10), which could be exposed at the sediment surface or be redistributed from underpier areas to open-water areas. The amount of mixing of open-water sediments with underpier sediments (e.g., sediment exchange) is a factor that affects overall natural recovery. While the box model predicts a certain level of exchange of underpier sediment (including residuals left behind by diver-assisted hydraulic dredging) to open-water areas, redistribution or exposure of contaminated sediment in areas with in situ treatment has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 2C+(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place (Section 9.9.3.1). The Institutional Controls Plan will include at a minimum the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 2C+(12) to be adaptively managed, as needed, based on new information.

9.9.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-14).

9.9.5 Short-term Effectiveness

9.9.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 10-year construction period for Alternative 2C+(12). Fish and shellfish tissue concentrations are predicted to remain elevated for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (84,500, 121,500, and 12,900, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, amount of diver-assisted hydraulic dredging, transportation, and duration of the remediation activities of Alternative 2C+(12) (Appendix I). This alternative includes 2 acres of diver-assisted hydraulic dredging in underpier locations over two construction seasons, which has intrinsic high safety concerns, especially in deeper water and under structures.

9.9.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations, which for Alternative 2C+(12) would occur over ten construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 2C+(12) (96 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 2C+(12), the benthic community within approximately 4.1 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by active remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative would consume regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 280,000 cy of imported granular material would be used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-14). The landfill capacity consumed by Alternative 2C+(12) is proportional to the volume of dredged material removed and disposed of in the landfill (1,090,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal energy consumed (from diesel fuel combustion and water treatment due to diver-assisted hydraulic dredging, respectively) during the remediation activities of Alternative 2C+(12) is estimated to be 1.2×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 2C+(12) are presented in Appendix I. Implementation of this alternative would result in approximately 18,100 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 6.3 and 6.2 metric tons, respectively), CO (78 metric tons), HCs (24 metric tons), VOCs (25 metric tons), NO_x (150 metric tons), and SO_2 (0.29 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 4,281 acres-year (Appendix I).

9.9.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 2C+(12) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[130]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 2C+(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 2C+(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 10 years (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

[130] As described in Section 9.1.2.3, the total number of years of construction could be reduced by 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

Alternative 2C+(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 10 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 10) for total PCBs and for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 10).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.9.6 Implementability

Alternative 2C+(12) has a construction period of 10 years, remediates 121 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-14). Anticipated access restrictions and placement methods of the activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

Alternative 2C+(12) also includes removal (2 acres; Table 9-14) in conjunction with in situ treatment in underpier areas. Implementability considerations, technical issues, and safety concerns on diver-assisted hydraulic dredging are similar to those described for Alternative 1C+(12) (Section 9.7.6).

A total of 15 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 2C+(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed as a contingency for Alternative 2C+(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.9.7 Cost

The total cost for Alternative 2C+(12) is $297 million, which includes estimated construction and non-construction costs of $233 and $64 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.9.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.10 Alternative 3B(12)

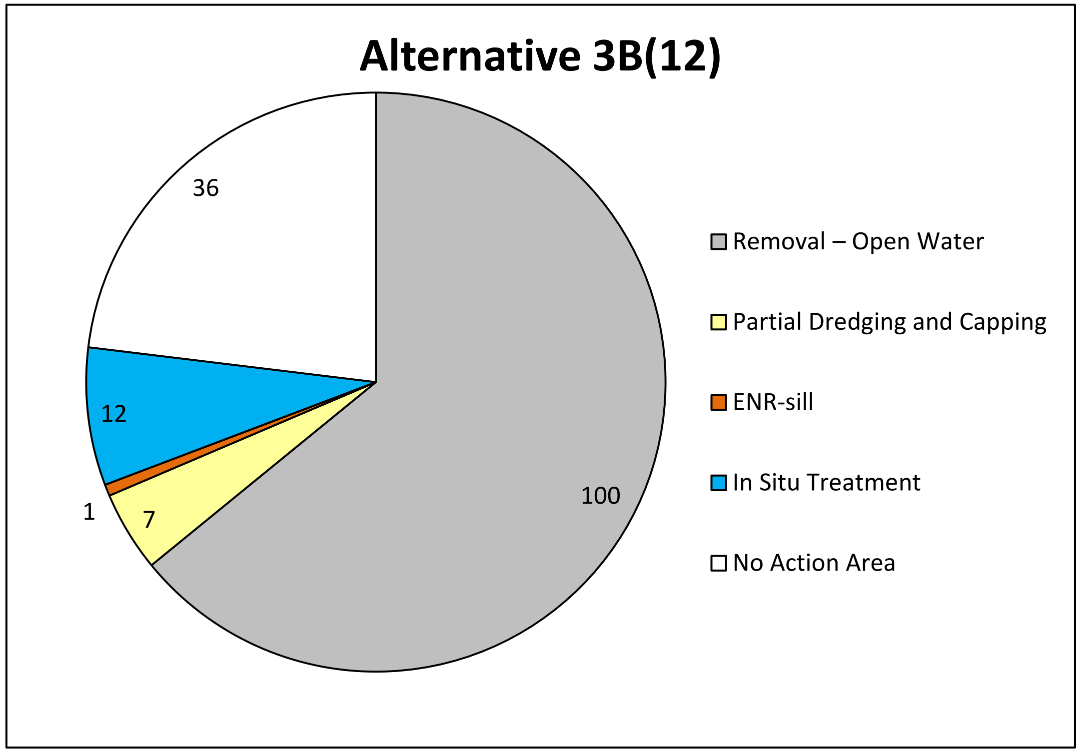
Table 9-15 presents a summary for Alternative 3B(12) including areas, volumes, construction timeframe, and costs.

9.10.1 Overall Protection of Human Health and the Environment

Alternative 3B(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under low bridges), and in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-15). Alternative 3B(12)

Table 9-15
Alternative 3B(12) Summary

Areas (acres)	
Removal – Open Water	100
Partial Dredging and Capping	7
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	1
MNR	0
Hydraulic Dredging Followed by In situ Treatment	0
In Situ Treatment	12
No Action Area	36
Volumes (cy)	
Total Removal Volume	960,000
Total Placement Volume	270,000
Construction Timeframe (years)	
Construction Time	10
Costs ($ Million)	
Construction Costs	233
Non-construction Costs	65
Total Costs (rounded)	298



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

has an estimated construction period of 10 years, during which the community, workers, and the environment would be affected as described in Section 9.10.5.

A description of PRG achievements for Alternative 3B(12) is listed below (Table 9-8):

- Alternative 3B(12) does not achieve the natural background-based PRG for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).
- This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 7 acres of partial dredging and capping, 1 acres of ENR-sill, and 12 acres of in situ treatment.

Considering the factors described in this section, Alternative 3B(12) achieves the threshold criterion of overall protection of human health and the environment.

9.10.2 Compliance with ARARs

Alternative 3B(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[131] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 3B(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

[131] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 3B(12) achieves the threshold criterion of compliance with ARARs.

9.10.3 Long-term Effectiveness and Permanence

9.10.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 3B(12) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 3B(12) (achievement of PRGs for each RAO is discussed in Section 9.10.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/ furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).

- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[132]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all other key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within ENR-sill and in situ treatment areas. Table 9-10 shows that the numbers of core stations with CSL and RAL/SQS exceedances remaining in areas that are partially removed and capped are 5 and 7, respectively; none would remain in ENR-sill areas; and one core greater than RAL/SQS would remain in areas with in situ treatment. The corresponding surface areas that leave some degree of contamination in the subsurface are 7 acres in partial dredging and capping, 1 acre in ENR-sill, and 12 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations would exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (100 acres), which results in a much smaller percentage of the waterway with residual contamination left in place.

[132] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

9.10.3.2 Adequacy and Reliability of Controls

Alternative 3B(12) removes 100 acres of contaminated sediment from the EW and yields a long-term permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals. Areas that undergo partial dredging and capping (7 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

One acre of ENR-sill and 12 acres of in situ treatment under Alternative 3B(12) will require a higher level of monitoring and may require contingency actions (Table 9-15). As described for Alternative 1A(12), ENR-sill and in situ treatment are potentially less reliable technologies than others (i.e., dredging, capping), because of several uncertain components of natural recovery and other mechanisms that can easily expose buried contaminated sediment in ENR and in situ treatment areas. Some uncertainty is also associated with actual reductions in bioavailability as a result of in situ treatment, along with the potential for higher propwash events to redistribute some of the in situ treatment material. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates these areas have unacceptable performance (see Section 9.5.3.2). Alternative 3B(12) only leaves contaminated subsurface sediment in place in in situ treatment areas (see Section 9.10.3.1 and Table 9-10). Therefore, some level of exposure of the sediment surface or redistribution from underpier areas to open-water areas is anticipated.

Alternative 3B(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place (Section 9.10.3.1). The Institutional Controls Plan will include, at a minimum, the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls, would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 3B(12) to be adaptively managed, as needed, based on new information.

9.10.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-15).

9.10.5 Short-term Effectiveness

9.10.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 10-year construction period for Alternative 3B(12). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (88,600, 114,500, and 12,800, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, transportation, and duration of the remediation activities of Alternative 3B(12)(see Appendix I).

9.10.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment expected to occur to some degree during dredging operations, which for Alternative 3B(12) would occur over ten construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 3B(12) (100 acres) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 3B(12), the benthic community within approximately 5.8 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by active remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative would consume regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 270,000 cy of imported granular material is used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-15). The landfill capacity consumed by Alternative 3B(12) is proportional to the volume of dredged material removed and disposed of in the landfill (1,150,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal and electrical energy consumed from diesel fuel combustion during the remediation activities of Alternative 3B(12) are estimated to be 1.3×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 3B(12) are presented in Appendix I. Implementation of this alternative would result in approximately 18,000 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 6.4 and 6.3 metric tons, respectively), CO (77 metric tons), HCs (23 metric tons), VOCs (24 metric tons), NO_x (160 metric tons), and SO_2 (0.29 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 4,257 acres-year (Appendix I).

9.10.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 3B(12) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[133]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 3B(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 3B(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 3B(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 10 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

[133] As described in Section 9.1.2.3, the total number of years of construction could be reduced by 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 10) for total PCBs and for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 10).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, uncertain (see Section 9.15).

9.10.6 Implementability

Alternative 3B(12) has a construction period of 10 years, remediates 121 acres, and is administratively implementable. An additional technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-15). Anticipated access restrictions and placement methods of activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

A total of 13 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 3B(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed as a contingency for Alternative 3B(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.10.7 Cost

The total cost for Alternative 3B(12) is $298 million, which includes estimated construction and non-construction costs of $233 and $65 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.10.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.11 Alternative 3C+(12)

Table 9-16 presents a summary for Alternative 3C+(12) including areas, volumes, construction timeframe, and costs.

9.11.1 Overall Protection of Human Health and the Environment

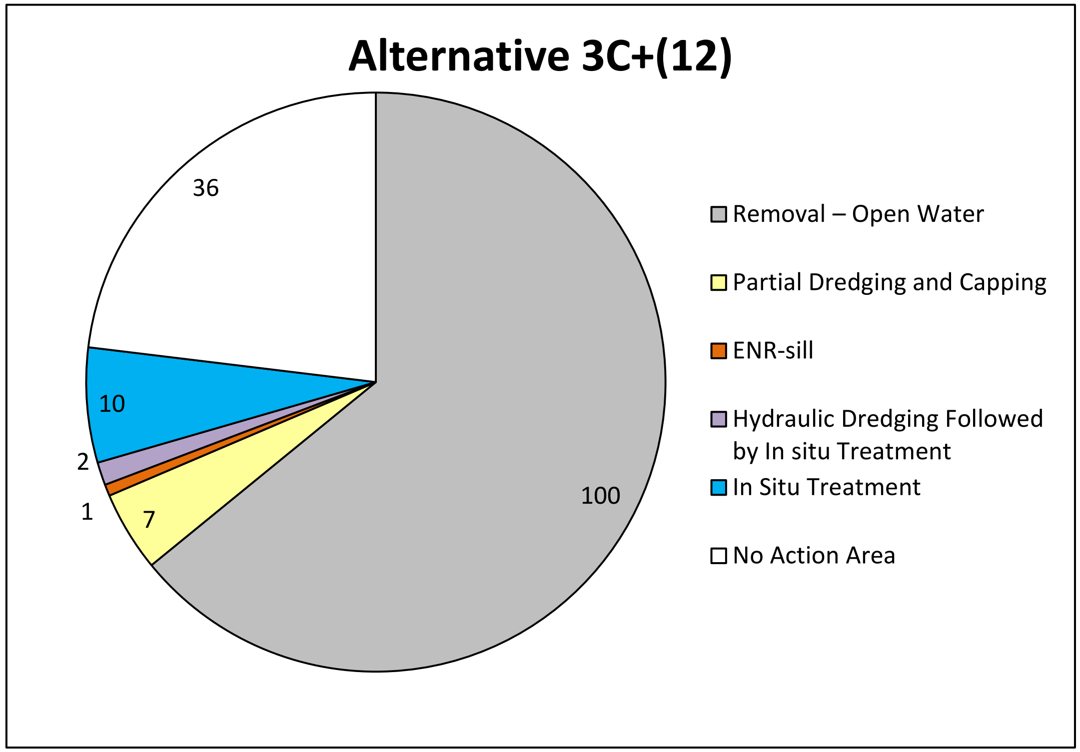
Alternative 3C+(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under low bridges), diver-assisted hydraulic dredging followed by in situ treatment, and in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-16). Alternative 3C+(12) has an estimated construction period of 10 years, during which the community, workers, and the environment would be affected as described in Section 9.11.5.

A description of PRG achievements for Alternative 3C+(12) is listed below (Table 9-8):

- Alternative 3C+(12) does not achieve the natural background-based PRG for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2). This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Table 9-16
Alternative 3C+(12) Summary

Areas (acres)	
Removal – Open Water	100
Partial Dredging and Capping	7
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	1
MNR	0
Hydraulic Dredging Followed by In situ Treatment	2
In Situ Treatment	10
No Action Area	36
Volumes (cy)	
Total Removal Volume	960,000
Total Placement Volume	270,000
Construction Timeframe (years)	
Construction Time	10
Costs ($ Million)	
Construction Costs	244
Non-construction Costs	66
Total Costs (rounded)	310



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 7 acres of partial dredging and capping, 1 acres of ENR-sill, 2 acres of diver-assisted hydraulic dredging followed by in situ treatment, and 10 acres of in situ treatment.

Considering the factors described in this section, Alternative 3C+(12) achieves the threshold criterion of overall protection of human health and the environment.

9.11.2 Compliance with ARARs

Alternative 3C+(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[134] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 3C+(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain

[134] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).

- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.
A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 3C+(12) achieves the threshold criterion of compliance with ARARs.

9.11.3 Long-term Effectiveness and Permanence

9.11.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 3C+(12) significantly would reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 3C+(12) (achievement of PRGs for each RAO is discussed in Section 9.11.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).
- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[135]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all other key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside

[135] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

of the dredge and partial dredge and cap areas, within ENR-sill and in situ treatment areas). Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 5 and 7, respectively; none would remain in ENR-sill areas; and one core greater than RAL/SQS would remain in areas with in situ treatment. The corresponding surface areas that leave some degree of contamination in the subsurface are 7 acres in partial dredging and capping, 1 acre in ENR-sill, and 10 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (102 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.11.3.2 Adequacy and Reliability of Controls

Alternative 3C+(12) removes 102 acres (including 2 acres with diver-assisted hydraulic dredging in underpier areas) of contaminated sediment from the open-water and underpier areas of the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals left behind by diver-assisted hydraulic dredging. Areas that undergo partial dredging and capping (7 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

The 12 acres of in situ treatment (in underpier areas) and 1 acre of ENR-sill (under low bridges) under Alternative 3C+(12) will require a higher level of monitoring and may require contingency actions (Table 9-16). As described for Alternative 1A(12), ENR-sill and in situ treatment are potentially less reliable technologies than others (i.e., dredging, capping) because: a) sedimentation rates and contaminant input concentrations are uncertain components of natural recovery; and b) other mechanisms that can expose buried contaminated sediment in ENR-sill and in situ treatment areas. Some uncertainty is also associated with actual reductions in bioavailability as a result of in situ treatment, along with the potential for higher propwash events to redistribute some of the in situ treatment material. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates ENR-sill and in situ treatment areas have unacceptable performance (see Section 9.5.3.2). Alternative 3C+(12) only leaves contaminated subsurface sediment in place in in situ treatment areas (see Section 9.11.3.1 and Table 9-10) that could be exposed at the sediment surface or be redistributed from underpier areas to open-water areas. The amount of mixing of open-water sediments with underpier sediments (e.g., sediment exchange) is a factor that affects overall natural recovery. While the box model predicts a certain level of exchange of underpier sediment (including residuals left behind by diver-assisted hydraulic dredging) to open-water areas, redistribution or exposure of contaminated sediment in areas with in situ treatment has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 3C+(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place (Section 9.11.3.1). The Institutional Controls Plan will include at a minimum the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 3C+(12) to be adaptively managed, as needed, based on new information.

9.11.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-16).

9.11.5 Short-term Effectiveness

9.11.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 10-year construction period for Alternative 3C+(12). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (89,200, 114,400, and 12,800, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, amount of diver-assisted hydraulic dredging, transportation, and duration of the remediation activities of Alternative 3C+(12) (Appendix I). This alternative includes 2 acres of diver-assisted hydraulic dredging in underpier locations over two construction seasons, which has intrinsic high safety concerns, especially in deeper water and under structures.

9.11.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment expected to occur to some degree during dredging operations, which for Alternative 3C+(12) would occur over ten construction seasons. The use of BMPs for reducing, the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 3C+(12) (102 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 3C+(12), the benthic community within approximately 5.8 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative would consume regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 270,000 cy of imported granular material would be used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-16). The landfill capacity consumed by Alternative 3C+(12) is proportional to the volume of dredged material removed and disposed of in the landfill (1,150,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal and electrical energy consumed (from diesel fuel combustion and water treatment due to diver-assisted hydraulic dredging, respectively) during the remediation activities of Alternative 3C+(12) are estimated to be 1.3×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 3C+(12) are presented in Appendix I. Implementation of this alternative would result in approximately 18,100 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 6.6 and 6.5 metric tons, respectively), CO (83 metric tons), HCs (25 metric tons), VOCs (26 metric tons), NO_x (160 metric tons), and SO_2 (0.3 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 4,281 acres-year (Appendix I).

9.11.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 3C+(12) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[136]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 3C+(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 3C+(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 3C+(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 10 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

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[136] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

For RAO 3, PRGs are predicted to achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 10) for total PCBs and for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 10).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.11.6 Implementability

Alternative 3C+(12) has a construction period of 10 years, remediates 121 acres, and is administratively implementable. An additional technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-16). Anticipated access restrictions and placement methods of the activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

Alternative 3C+(12) also includes limited removal (2 acres; Table 9-16) in conjunction with in situ treatment in underpier areas. Implementability considerations, technical issues, and safety concerns on diver-assisted hydraulic dredging are similar to those described for Alternative 1C+(12) (Section 9.7.6).

A total of 13 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 3C+(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed as a contingency for Alternative 3C+(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.11.7 Cost

The total cost for Alternative 3C+(12) is $310 million, which includes estimated construction and non-construction costs of $244 and $66 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.11.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.12 Alternative 2C+(7.5)

Table 9-17 presents a summary for Alternative 2C+(7.5) including areas, volumes, construction timeframe, and costs.

9.12.1 Overall Protection of Human Health and the Environment

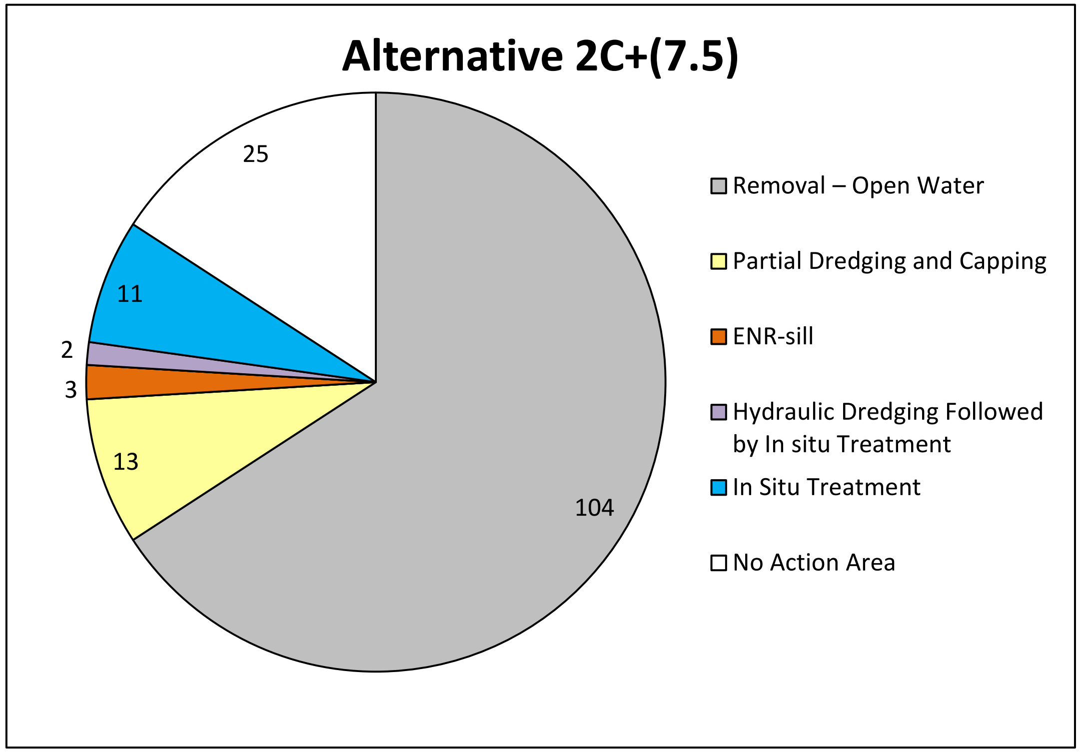
Alternative 2C+(7.5) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under low bridges), diver-assisted hydraulic dredging followed by in situ treatment, and in situ treatment (underpier areas). This alternative addresses 132 acres of contaminated sediment through these remedial technologies (Table 9-17). Alternative 2C+(7.5) has an estimated construction period of 11 years, during which the community, workers, and the environment would be affected as described in Section 9.12.5.

A description of PRG achievements for Alternative 2C+(7.5) is listed below (Table 9-8):

- Alternative 2C+(7.5) does not achieve the natural background-based PRG for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).

Table 9-17
Alternative 2C+(7.5) Summary

Areas (acres)	
Removal – Open Water	104
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	3
MNR	0
Hydraulic Dredging Followed by In situ Treatment	2
In Situ Treatment	11
No Action Area	25
Volumes (cy)	
Total Removal Volume	1,010,000
Total Placement Volume	290,000
Construction Timeframe (years)	
Construction Time	11
Costs ($ Million)	
Construction Costs	257
Non-construction Costs	69
Total Costs (rounded)	326



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).
- This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 13 acres of partial dredging and capping, 3 acres of ENR-sill, 2 acres of diver-assisted hydraulic dredging followed by in situ treatment, and 11 acres of in situ treatment.

Considering the factors described in this section, Alternative 2C+(7.5) achieves the threshold criterion of overall protection of human health and the environment.

9.12.2 Compliance with ARARs

Alternative 2C+(7.5) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[137] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health

[137] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 2C+(7.5) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 2C+(7.5) achieves the threshold criterion of compliance with ARARs.

9.12.3 Long-term Effectiveness and Permanence

9.12.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 2C+(7.5) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 2C+(7.5) (achievement of PRGs for each RAO is discussed in Section 9.12.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).
- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[138]

[138] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all other key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 μg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 μg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within ENR-sill and in situ treatment areas. Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 8 and 13, respectively; one greater than CSL and two greater than RAL/SQS would remain in ENR-sill areas; and one exceeding the RAL/SQS would remain in in situ treatment areas. The corresponding surface areas that leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 3 acres in ENR-sill, and 11 acres in in situ treatment. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (106 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.12.3.2 Adequacy and Reliability of Controls

Alternative 2C+(7.5) removes 106 acres (including 2 acres with diver-assisted hydraulic dredging in underpier areas) of contaminated sediment from the open-water and underpier areas of the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals left behind by diver-assisted hydraulic dredging. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

Only 3 acres of ENR-sill (under low bridges) and 13 acres of in situ treatment (underpier areas) under Alternative 2C+(7.5) will require a higher level of monitoring and may require contingency actions (Table 9-17). However, this alternative only leaves contaminated subsurface sediment above the CSL in place in ENR-sill areas (see Section 9.12.3.1 and Table 9-17) that could expose at the sediment surface or be redistributed from underpier areas to open-water areas. The amount of mixing of open-water sediments with underpier sediments (e.g., sediment exchange) is a factor that affects overall natural recovery. While the box model predicts a certain level of exchange of underpier sediment (including residuals left behind by diver-assisted hydraulic dredging) to open-water areas, redistribution or exposure of contaminated sediment in areas with in situ treatment has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 2C+(7.5) requires an Institutional Controls Plan because the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary). The Institutional Controls Plan will include, at a minimum, the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls, would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 2C+(7.5) to be adaptively managed, as needed, based on new information.

9.12.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 13 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-17).

9.12.5 Short-term Effectiveness

9.12.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 11-year construction period for Alternative 2C+(7.5). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (94,000, 125,600, and 13,800, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, amount of diver-assisted hydraulic dredging, transportation, and duration of the remediation activities of Alternative 2C+(7.5) (Appendix I). This alternative includes 2 acres of diver-assisted hydraulic dredging in underpier locations over two construction seasons, which has intrinsic high safety concerns, especially in deeper water and under structures.

9.12.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations, which for Alternative 2C+(7.5) would occur over 11 construction seasons. The use of BMPs for reducing, the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 2C+(7.5) (106 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas) and over the interior unremediated areas (15 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 2C+(7.5), the benthic community within approximately 4.7 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by active remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative would consume regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 290,000 cy of imported granular material is used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-17). The landfill capacity consumed by Alternative 2C+(7.5) is proportional to the volume of dredged material removed and disposed of in the landfill (1,210,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal and electrical energy consumed (from diesel fuel combustion and water treatment due to diver-assisted hydraulic dredging, respectively) during the remediation activities of Alternative 2C+(7.5) are estimated to be 1.3×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 2C+(7.5) are presented in Appendix I. Implementation of this alternative would result in approximately 19,100 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 7.0 and 6.8 metric tons, respectively), CO (85 metric tons), HCs (26 metric tons), VOCs (27 metric tons), NO_x (170 metric tons), and SO_2 (0.31 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 4,518 acres-year (Appendix I).

9.12.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 2C+(7.5) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[139]

For RAO 1, the natural background based PRGs for total PCB and dioxins/furans are not achieved by Alternative 2C+(7.5) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 2C+(7.5) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 11 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 11 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 2C+(7.5) is also predicted to achieve 7 mg/kg dw for arsenic by year 11 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

[139] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 11) for total PCBs and for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 11).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.12.6 Implementability

Alternative 2C+(7.5) has a construction period of 11 years, remediates 132 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (13 acres; Table 9-17). Anticipated access restrictions and placement methods of the activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

Alternative 2C+(7.5) also includes removal (2 acres; Table 9-17) in conjunction with in situ treatment in underpier areas. Implementability considerations, technical issues, and safety concerns on diver-assisted hydraulic dredging are similar to those described for Alternative 1C+(12) (Section 9.7.6).

A total of 16 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 2C+(7.5); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed as a contingency for Alternative 2C+(7.5) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.12.7 Cost

The total cost for Alternative 2C+(7.5) is $326 million, which includes estimated construction and non-construction costs of $257 and $69 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.12.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.13 Alternative 3E(7.5)

Table 9-18 presents a summary for Alternative 3E(7.5) including areas, volumes, construction timeframe, and costs.

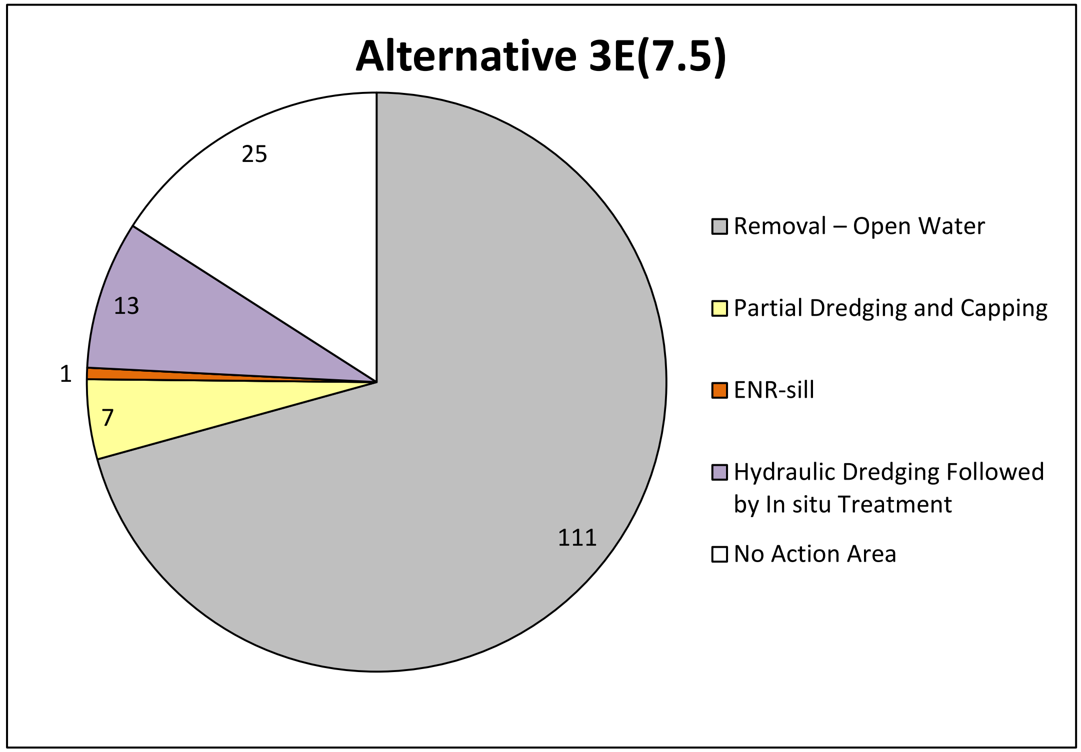
9.13.1 Overall Protection of Human Health and the Environment

Alternative 3E(7.5) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under low bridges), and diver-assisted hydraulic dredging followed by in situ treatment (underpier areas). This alternative addresses 132 acres of contaminated sediment through these remedial technologies (Table 9-18). Alternative 3E(7.5) has an estimated construction period of 13 years, during which the community, workers, and the environment would be affected as described in Section 9.13.5.

A description of PRG achievements for Alternative 3E(7.5) is listed below (Table 9-8):

Table 9-18
Alternative 3E(7.5) Summary

Areas (acres)	
Removal – Open Water	111
Partial Dredging and Capping	7
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	1
MNR	0
Hydraulic Dredging Followed by In situ Treatment	13
In Situ Treatment	0
No Action Area	25
Volumes (cy)	
Total Removal Volume	1,080,000
Total Placement Volume	270,000
Construction Timeframe (years)	
Construction Time	13
Costs ($ Million)	
Construction Costs	333
Non-construction Costs	78
Total Costs (rounded)	411



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

- Alternative 3E(7.5) does not achieve the natural background-based PRG for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2). This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 7 acres of partial dredging and capping, 1 acre of ENR-sill, and 13 acres of in situ treatment.

Considering the factors described in this section, Alternative 3E(7.5) achieves the threshold criterion of overall protection of human health and the environment.

9.13.2 Compliance with ARARs

Alternative 3E(7.5) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[140] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 3E(7.5) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

[140] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 3E(7.5) achieves the threshold criterion of compliance with ARARs.

9.13.3 Long-term Effectiveness and Permanence

9.13.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 3E(7.5) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a), and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 3E(7.5) (achievement of PRGs for each RAO is discussed in Section 9.13.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (4 for Adult Tribal, 9 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).

- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[141]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all other key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within ENR-sill and in situ treatment areas. Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 5 and 7, respectively, and none would remain in ENR-sill. The corresponding surface areas that leave some degree of contamination in the subsurface are 7 acres in partial dredging and capping, and 1 acre in ENR-sill. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (124 acres, including 13 acres with diver-assisted hydraulic dredging in underpier areas), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.13.3.2 Adequacy and Reliability of Controls

Alternative 3E(7.5) removes 124 acres (including 13 acres with diver-assisted hydraulic dredging in underpier areas) of contaminated sediment from the open-water and underpier

[141] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

areas of the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals left behind by diver-assisted hydraulic dredging. Areas that undergo partial dredging and capping (7 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

Only 1 acre of ENR-sill (under low bridges) and 13 acres of in situ treatment (after diver-assisted hydraulic dredging in underpier areas) under Alternative 3E(7.5) will require a higher level of monitoring and may require contingency actions (Table 9-17). However, this alternative does not leave any contaminated subsurface sediment above the RALs in place in ENR-sill areas (see Section 9.12.3.1 and Table 9-17) that could expose buried contaminated sediment.

Alternative 3E(7.5) requires an Institutional Controls Plan because the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary). The Institutional Controls Plan will include, at a minimum, the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls, would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 3E(7.5) to be adaptively managed, as needed, based on new information.

9.13.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 13 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-18).

9.13.5 Short-term Effectiveness

9.13.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 13-year construction period for Alternative 3E(7.5). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (100,000, 118,200, and 13,800, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, amount of diver-assisted hydraulic dredging, transportation, and duration of the remediation activities of Alternative 3E(7.5) (Appendix I). This alternative includes 13 acres of diver-assisted hydraulic dredging in underpier locations over twelve construction seasons, which has intrinsic high safety concerns, especially in deeper water and under structures.

9.13.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations, which for Alternative 3E(7.5) would occur over 13 construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 3E(7.5) (124 acres, including 13 acres with diver-assisted hydraulic dredging in underpier areas) and over the interior unremediated areas (15 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 3E(7.5), the benthic community within approximately 6.6 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by active remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative would consume regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 270,000 cy of imported granular material is used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-18). The landfill capacity consumed by Alternative 3E(7.5) is proportional to the volume of dredged material removed and disposed of in the landfill (1,300,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal and electrical energy consumed (from diesel fuel combustion and water treatment due to diver-assisted hydraulic dredging, respectively) during the remediation activities of Alternative 3E(7.5) are estimated to be 1.4×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 3E(7.5) are presented in Appendix I. Implementation of this alternative would result in approximately 22,700 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 8.3 and 8.2 metric tons, respectively), CO (120 metric tons), HCs (39 metric tons), VOCs (40 metric tons), NO_x (190 metric tons), and SO_2 (0.39 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 5,369 acres-year (Appendix I).

9.13.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 3E(7.5) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[142]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 3E(7.5) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 3E(7.5) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 13 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-6} order of magnitude excess cancer risk for the Child Tribal RME by year 13 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 3E(7.5) is also predicted to achieve 7 mg/kg dw for arsenic in 13 years (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

[142] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 13) for total PCBs and for the other key benthic risk driver COCs.
The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 13).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.13.6 Implementability

Alternative 3E(7.5) has a construction period of 13 years, remediates 132 acres, and is administratively implementable. A major implementability challenge for Alternative 3E(7.5) is the extensive use of diver-assisted hydraulic dredging in underpier areas. This alternative assumes the removal, to the extent practicable, of all 13 acres above RALs in underpier areas (Table 9-18). Technical considerations and issues and safety concerns for diver-assisted hydraulic dredging are similar to those described for Alternative 1C+(12), but of greater magnitude considering the increased area of diver-assisted hydraulic dredging (Section 9.7.6).

An additional technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (13 acres; Table 9-18). Anticipated access restrictions and placement methods of the activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

A total of 14 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 3E(7.5); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed as a contingency for Alternative 3E(7.5) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

The long construction period, large total removal volume, and high potential for low RALs triggering significant additional actions from recontamination are other important implementability considerations for Alternative 3E(7.5).

9.13.7 Cost

The total cost for Alternative 3E(7.5) is $411 million, which includes estimated construction and non-construction costs of $333 and $78 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.13.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.14 Recontamination Potential

As presented in Section 2.11.3, potential sources of contaminants to media such as air, soil, groundwater, and surface water or to impervious surfaces may migrate to the EW through various pathways. Potential sources can be either historical or ongoing. These pathways include the following:

- Direct discharge into the EW (e.g., CSOs, stormwater, or sheetflow from properties immediately adjacent to the waterway)
- Upstream inputs
- Groundwater discharge
- Bank erosion
- Atmospheric deposition
- Spills and/or leaks to the ground, surface water, or directly into the EW
- Abrasion and leaching of treated-wood structures

As discussed in the SRI (Windward and Anchor QEA 2014), direct discharges and upstream inputs are the predominant sources of sediment inputs to the EW; therefore, those two sources are important to discuss the potential for recontamination. In addition, atmospheric deposition in comparison to direct discharge is also further evaluated. Remaining pathways were determined to be incidental and localized. Most of these pathways are episodic—such as spills and abrasion of treated-wood structures, or highly localized—such as groundwater discharge, bank erosion, and leaching of treated-wood structures, and were not further evaluated for recontamination potential. Potential concerns from sources that can be highly localized will be further investigated during design. Direct discharge and upstream inputs and direct atmospheric deposition onto the waterway itself were further evaluated in this section to assess recontamination potential.

As discussed in Section 9 of the SRI (Windward and Anchor QEA 2014), multiple external sources of contaminant inputs to the EW exist. They reflect both regional and local sources and are the primary factors influencing the surface sediment contaminant concentrations in the long term following any cleanup. This section includes an assessment of the potential for recontamination based on incoming sediment deposition from both upstream and EW lateral sources that deposit in the waterway. This section also summarizes the evaluation of direct atmospheric deposition to the waterway presented in Appendix K. For simplicity, "recontamination" is defined as contaminant concentrations in surface sediments that return to unacceptable levels after a cleanup (e.g., concentrations above any of the RALs), which triggers the need for additional monitoring or some other action, depending on the source. Diffuse, urban sources external to the EW are a key potential pathway of recontamination. Potential localized resuspension and re-deposition of existing contaminated sediment within the EW may also contribute to recontamination. If surface sediment recontamination occurs, it will reflect the aggregate inputs of these internal and external sources, but action may not be needed depending on the level of recontamination observed. Source control actions (see Section 2.12), including those upstream of the site, will affect long-term contaminant concentrations in EW sediments.

9.14.1 Direct Discharge and Upstream Inputs

The recontamination potential within the EW has been evaluated based on incoming sediment deposition from both upstream and EW lateral sources for all nine risk driver COCs. Surface concentrations of deposited sediment were estimated throughout the EW on a

50-foot by 50-foot grid, based on results of the PTM evaluation (see Section 5.4.1 and Appendix B, Part 1) that provide predictions of spatial variation in EW lateral solids deposition at the same resolution.[143] As described in Section 5.4.3, deposition from upstream sources was assumed to be constant throughout the EW for the recontamination evaluation. In situ surface concentrations at year 0 post-construction were assumed to be zero for all COCs for all alternatives in order to focus the evaluation on recontamination potential associated with the contribution of incoming solids deposition, including EW laterals. Therefore, the conclusions of the recontamination evaluation are applicable to all alternatives.

Surface concentrations of deposited sediments in the EW were calculated for all nine key risk driver COCs based on base case (mid-range) assumptions for solids deposition and chemistry (see Section 5.4.5). Current solids and chemistry assumptions for EW lateral inputs were applied for years 1 through 10 post-construction, and future solids and chemistry assumptions (after additional control of sources) were applied to EW lateral inputs for years 11 through 30 post-construction. Surface concentrations are based on initial deposition patterns predicted by the PTM, and do not take into account mixing or spreading of deposited sediments due to vessel operations in the EW (e.g., propwash).

Appendix J (see Figures 7a and 7b) contains maps highlighting areas where surface concentrations of deposited sediments are predicted to exceed RALs for one or more of the nine key risk driver COCs and, for information purposes, where the seven benthic risk driver COCs were predicted to exceed benthic numerical CSL values. These maps represent mid-range value assumptions (base case) for incoming solids inputs and associated chemistry. Maps showing surface concentrations of deposited sediments for the low and high bounding calculations for total PCBs, dioxins/furans, and BEHP are also provided in Appendix J in Figures 8a-b, 9a-b, and 10a-b, respectively.

Figures 9-7a and 9-7b shows areas that may have the potential to recontaminate based on the results of this evaluation. Areas were identified based on surface concentrations predicted to

[143] Deposition patterns predicted by the PTM represent initial deposition from EW lateral sources and do not include redistribution of deposited sediments due to anthropogenic activity (e.g., propwash).

exceed the RAL for any modeled COC at year 10 post-construction (prior to source control being implemented) and at years 10-30 (long-term) for mid-range value assumptions (base case). COCs that may have an increased potential to recontaminate in specific areas include BEHP, 1,4-dichlorobenzene, mercury, and dioxins/furans, generally in localized areas near specific outfalls. Modeled concentrations for 1,4-dichlorobenzene are a result of conservatively using elevated measurements in the modeling dataset, which are more representative of a source that has since been controlled; therefore, exceedances are not likely to persist. Mercury's potential exceedance is predicted to occur in a single grid cell in the EW, where there are only a few samples with relatively high concentrations and variability. Because BEHP and dioxins/furans are ubiquitous components of PVC plastics and combustion processes, respectively, marginal RAL exceedances may occur in the immediate vicinity of outfalls, consistent with other urban areas.

This evaluation does not account for redistribution from propwash or other anthropogenic forces, which would likely decrease the value of predicted concentrations at specific elevated grid cells, but could also result in a slightly larger area with elevated concentrations. In addition, all nearshore outfalls were assigned the same chemistry assumptions in the evaluation (see Appendix B, Part 4). Actual chemistry data from an individual outfall may be different. Therefore, some locations in the EW identified as having elevated recontamination potential may not be representative of actual deposited solids concentrations in those areas.

Areas modeled to have elevated recontamination potential are defined as specific grid cells predicted to have elevated concentrations. The results do not mean recontamination is expected to occur, but that the potential exists based on the modeling assumptions used. It is anticipated that these areas will be considered during the design phase as areas that may require additional source evaluation and control and targeted monitoring following remediation. Uncertainty associated with this evaluation is discussed in Section 9.15 and Appendix J.

9.14.2 Direct Atmospheric Deposition

Contributions from direct atmospheric deposition[144] to the waterway were evaluated in Appendix K. These qualitative assessments indicate that direct atmospheric deposition masses of BEHP and dioxins/furans may be significant relative to mass from the direct discharge pathway. These inputs are distributed across the EW surface area and, while contributing some input of contaminants to the EW, they are not expected to create any localized recontamination concerns. Direct atmospheric deposition masses of arsenic, HPAH, mercury, and total PCBs to the EW water surface are small compared to the direct discharge pathway masses. Note that direct discharge masses also include indirect atmospheric deposition to the contributing drainage basins, which was not estimated separately due to uncertainties in quantifying the indirect pathway.

9.15 Uncertainty Considerations

9.15.1 Surface Sediment Concentration Predictions

9.15.1.1 Bed Replacement Values and Residuals

Sediment bed replacement values are a key input in establishing post-construction (Time 0) concentrations and affect the short-term model-predicted outcomes. For total PCBs, a range of replacement values were developed for remediated areas and interior unremediated areas using low and high residuals thicknesses and concentrations (this range was intended to capture the uncertainty associated with any of the variables that contribute to the actual post-construction surface sediment concentration; Appendix B, Part 3A). However, as shown in Figures 3a, 3b, 4a, 4b, 5a, and 5b in Appendix J, long-term site-wide concentrations are more influenced by other variables, particularly physical factors like extent and depth of sediment mixing, NSRs, and incoming Green River sediment concentrations.

Actual surface sediment concentration immediately following construction in the EW will be largely dependent on dredge residuals concentrations and thickness. Thickness of dredge cut, type of dredge equipment, location-specific sediment characteristics, and use of BMPs

144 The indirect atmospheric deposition onto the upland drainage basins also contributes to the direct discharge pathway, but the contribution of such atmospheric deposition to the total direct discharges was not estimated as part of this evaluation.

will affect the dredge residuals thickness. The concentration of sediment being dredged (especially the last pass for dredging areas where multiple passes are required) also varies throughout the EW and will influence dredge residuals concentrations. As described in FS Appendix B, Part 5, variables that affect the dredge residuals thickness, concentration, and distribution include hydrodynamic and operational conditions within the EW during dredging and placement of RMC, including water depth, anticipated duration it would take to place clean material over the entire open-water remediation area, and frequency of ongoing vessel traffic in the EW that causes sediment resuspension and sediment bed mixing.

Other factors that could affect replacement value are evaluated in FS Appendix B, Part 5, including sand cover thickness (RMC), which has minimal effect on replacement values, and organic carbon content of sand cover, which is expected to rebound to baseline levels of organic carbon within a few years following RMC placement due to incoming sediment organic carbon concentrations and the load of organic material that accumulates from biological activity at the site (Appendix B, Part 5).

9.15.1.2 SWAC Values (Box Model) and Point Surface Concentrations (Point Mixing Model)

Uncertainty in predictions of SWAC values (box model evaluation) and point surface concentrations (point mixing model evaluation) are a result of uncertainty in input parameters (i.e., NSRs, chemistry assumptions) and uncertainty induced by the methodology used to complete the calculations. This section provides a brief overview of uncertainty in the calculations, which is discussed in detail in in Appendix J.

Uncertainties due to input data and methodology were assessed through sensitivity and bounding evaluations, which are discussed in detail in Section 2.3 of Appendix J. The results of these evaluations included an understanding of the impacts on SWAC and point surface concentrations due to variation in the values of input information. A summary of these impacts is provided below:

- Variability in Green River chemistry and range in its inputs has the largest impact on the SWAC values based on its potential range of values (approximately by up to 25% through year 10 post-construction and up to 45% by year 30 post-construction; see

Figures 3b and 4b in Appendix J). In the very long term (i.e., 30 years post-construction and beyond), Green River chemistry is the primary controlling parameter, because it is the primary determinant of the concentration the site will equilibrate to (i.e., the EW sediment concentrations reflect incoming Green River sediments). In the long term, higher Green River concentrations will result in higher site-wide SWACs. Green River chemistry has greater effect on alternatives with more active remediation and less reliance on natural recovery because site-wide SWACs are lower following construction for a more active alternative (largely due to the change in remediation technology in underpier areas), and therefore it equilibrates more rapidly to the concentration of incoming Green River sediments. The variation of all other variables considered falls within the envelope of potential SWAC values calculated by varying the Green River chemistry values.

- Other observations on SWACs outside of the impacts of Green River chemistry:
  - Variability in EW laterals chemistry has very little impact on predicted SWAC values (less than 5% at years 10 and 30 post-construction). Although input parameters from the LDW were not analyzed in the sensitivity analysis, lateral and resuspended LDW bedded sediment inputs are also expected to have very little impact on predicted SWAC values based on the total mass of loads to the EW from these two sources (0.7%; see Section 5.1) compared to other upstream sources (i.e., Green River; 99%).
  - A smaller NSR for the EW results in higher predicted SWAC values. The range in inputs for NSR can change predicted SWAC values by up to 15% through year 10 post-construction and up to 35% by year 30 post-construction. A higher NSR reduces the site-wide SWAC by reducing the time needed for the site to equilibrate to net incoming concentrations (i.e., increases the rate of natural recovery). Use of a variable NSR within the EW did not have any appreciable effect on the SWAC predictions, compared to best estimate calculations for any years. In general, NSR has a greater effect on alternatives with more reliance on natural recovery.
  - A larger value of maximum mixing depth results in lower predicted SWAC values (by approximately 5% at years 10 and 30 post-construction).
  - Decreasing the surface area of the EW that fully mixes within a set timeframe decreases the predicted SWAC values (by less than 5% at years 10 and 30 post-

construction, while increasing the timeframe for full mixing to occur increases the predicted SWAC values (by approximately 10% at year 10 post-construction and less than 5% at year 30 post-construction).

- Variability in bioavailability has little impact on predicted SWAC values. Percent reduction in bioavailability due to in situ treatment was one of the most sensitive parameter 0 to 10 years following construction, but was less sensitive in the long term. If in situ treatment is more effective at reducing bioavailability, then site-wide SWACs are predicted to be effectively lower. The range in inputs for the percent reduction in bioavailability due to in situ treatment can change predicted SWAC values by 30% at year 10, but its influence is reduced to up to 20% by year 30. This parameter only affects alternatives that employ in situ treatment.
- Modifying dredge residuals concentration results in a slightly greater change in predicted SWAC values than modifying dredge residuals thickness. Influence on year 30 post-construction SWAC values is slightly more for each factor, but each results in less than 10% change by year 30 post-construction.
- A smaller percentage exchanged between open water areas and underpier areas results in an increase in predicted SWAC values. Underpier exchange is another sensitive parameter 0 to 10 years following construction, but is not a very sensitive parameter in the long term. The model results predict that more underpier exchange would result in a higher temporary increase in site-wide SWAC following construction, due to the distribution of higher concentration underpier sediments into the larger, mostly remediated open-water areas. Less underpier exchange reduces the site-wide SWAC because the higher concentration sediments in the underpier remain localized. The range in inputs for underpier exchange can change predicted SWAC values by up to 20% at year 10 post-construction, but its influence is less than 10% by year 30. Underpier exchange has more effect on alternatives with MNR in the underpier area.

Sensitivity analysis was conducted for Alternatives 1A(12) and 2B(12), and a total of 18 different scenarios for Alternative 1A(12) and 20 different scenarios for Alternative 2B(12) were evaluated for total PCBs (see Appendix J).[145] The results of the sensitivity analysis were used to develop scenarios (combinations of input parameter values) that result in the lowest and highest SWAC predictions for Alternatives 1A(12) and 2B(12). This bounding analysis was done to quantify the maximum uncertainty in predicted SWAC values from the box model evaluation for all remedial alternatives. The lowest and highest bounding scenarios are determined using results of the sensitivity analysis for Alternatives 1A(12) and 2B(12) that showed which parameters caused the SWAC to increase or decrease (see Figures 3b and 4b in Appendix J).

The overall range of predicted SWACs for the highest and lowest bounding and base case scenarios suggests that SWAC values for the EW predicted by the box model could vary by up to +125% and -75% at year 10 and by up to +110% and -80% at year 30 for Alternatives 1A(12) and 2B(12), respectively (see Figures 5a and 5b in Appendix J). This is due primarily to the significant influence of the Green River chemistry and NSR in the EW. Based on four additional high and low bounding scenarios conducted on selected factors (which hold the Green River chemistry and NSR at base case values, while varying all other parameters), the SWAC values predicted by the box model vary by up to +50% and -40% at year 10 and by up to +20% and -25% at year 30 for Alternatives 1A(12) and 2B(12), respectively.

Figures 9-8a (Alternative 1A(12)) and 9-8b (Alternative 2B(12)) present graphically the results of the sensitivities in total PCB SWACs (calculated with the box model evaluation) for the eight model parameters, compared to base case, at years 10 and 30 post-construction. Based on Appendix J, while the sensitivity of the predicted SWAC calculations to individual parameters differed somewhat between the two alternatives, the range in predicted SWAC values based on the full range of uncertainty in the input parameters was similar for both alternatives. Therefore, interpretation and comparison of SWAC predictions to PRGs for each alternative presented in Section 9 should be considered carefully with respect to the uncertainty of the model.

[145] Alternative 1A(12) only has 18 scenarios because it does not have underpier in situ treatment, and therefore does not have sensitivity parameters for bioavailability.

The uncertainty of SWAC comparisons is further reinforced when considering analytical precision and field variability. Based on typical analytical relative percent differences and field variability, any individual or mean value within 20% of the cleanup standard is considered indistinguishable from the cleanup standard and, therefore, the measured value is in compliance.

Section 5.3.2 describes the range of incoming solids concentrations for all human health risk drivers. For arsenic, the low and high bounding range of incoming sediment concentrations is 7 mg/kg dw and 10 mg/kg dw, respectively. All alternatives achieve the long-term model predicted concentration, which for the base case is 9 mg/kg dw. If the incoming sediment concentration is closer to 7 mg/kg dw, the alternatives would meet the natural background PRG of 7 mg/kg dw, when using the UCL95 for calculating natural background.

For dioxins/furans, the low and high bounding range of incoming sediment concentrations is 2 ng TEQ/kg dw to 8 ng TEQ/kg dw. All active alternatives achieve the long-term model predicted concentration, which for the base case is 6 ng TEQ/kg dw.

9.15.1.3 Recontamination Evaluation (Grid Model)

This section provides a brief overview of uncertainty in the evaluation of recontamination potential, which is discussed in detail in Section 5.4 of Appendix J.

The primary sources of uncertainty for this evaluation are associated with input data for upstream solids and chemistry (discussed in Section 5.1.2) and EW lateral solids and chemistry (discussed in Section 5.1.3). Since the recontamination evaluation focused on impacts from EW laterals, uncertainty in solids inputs and chemistry assumptions for EW laterals was taken into account through a bounding evaluation as described in Section 4.5 of Appendix J.

A review of the bounding evaluation on the areas identified as having elevated recontamination potential show the following trends:

- All COCs evaluated in the bounding evaluation had fewer areas of concern for the low bounding simulation compared to the base case or high bounding simulation. Total PCBs had no areas of concern for the low bounding simulation.
- All COCs evaluated in the bounding evaluation had additional areas of concern based on the high bounding simulation. However, these areas represent a small portion of the EW area and do not extend far from source outfalls identified in the base run.
- Dioxins/furans had a small reduction in areas of concern once proposed future source control actions were accounted for. Proposed source control actions did not reduce total PCBs and BEHP locations or reduce their areas.

Considerations associated with the methodology used to evaluate recontamination potential that could introduce uncertainty in the evaluation include assumptions for surface concentrations at year 0 post-remediation and vertical mixing assumptions. Incorporation of predicted post-remediation conditions were not included in the predictions in order to focus the evaluation solely on impacts of incoming sediment deposition on recontamination potential to help inform source control. Actual concentrations over time would be impacted by what concentrations are actually present at Time 0. The deposition patterns predicted by the PTM for EW laterals do not take into account impacts of resuspension due to vessel operations. Therefore, deposition patterns predicted by the PTM (used as input for the grid model evaluation) for individual elevated grid cells would likely be more spread out, resulting in lower contaminant concentrations in those grid cells due to a wider distribution of deposited material over a larger area. This could result in a larger or smaller area with the potential for recontamination, depending on the concentration of the deposited material and the amount of propwash.

9.15.2 Other Uncertainties

The performance of the remedial technologies with respect to long-term effectiveness, short-term effectiveness, implementability, and cost represent an uncertainty in this analysis. In particular, the performance and technical challenges associated with the technologies for remediating underpier areas are a key uncertainty in this FS. The performance of MNR in underpier areas is less certain compared to the other remedial technologies (ENR-sill, in situ treatment, or removal); however, MNR poses very few technical challenges. While the performance of in situ treatment is considered more certain than for MNR, it still depends on a range of physical and chemical factors. In situ treatment also includes important technical challenges for placing material on steep slopes in difficult-to-access areas. Finally, diver-assisted hydraulic dredging is associated with large uncertainty in terms of both performance and technical implementability. Performance of diver-assisted hydraulic dredging is uncertain with respect to the quantity of contaminated sediment remaining due to conditions under piers (e.g., riprap interstices and debris). Technical implementability is also uncertain with respect to the construction timeframe, diver health and safety, and costs associated with removing underpier sediments in deep water.

The performance of the remedial technologies outside of underpier areas also have uncertainties, which are mitigated by adaptive management. Dredging results in the release of contaminants to the water column (which can elevate fish and shellfish tissue contaminant concentrations over the short term) and dredge residuals to the sediment surface. As described in Appendix A, full removal of all contaminated sediment is not possible in many areas near structures, where setbacks and stable slopes required for structure protection will leave some contaminated sediments behind. Long-term site-wide predictions will depend on the location and amount of sediment remaining adjacent to structures, and the potential for it to be disturbed from propwash. Measures will be incorporated into the design to address this remaining sediment, along with monitoring and adaptive management following construction.

Capping, partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment require ongoing monitoring and may need periodic maintenance. MNR performance may be slower or faster than predicted and may require additional monitoring or contingency actions. These uncertainties would be managed in the long term under the action alternatives by the required monitoring, contingency actions, and repairs as needed. Cost estimates in this FS include the costs of these long-term management activities. These activities would be enforceable requirements under a Consent Decree (or similar mechanism), and EPA is required to review the effectiveness of their selected remedy no less frequently than every 5 years.

In addition, uncertainty exists in the predictions of resident seafood tissue contaminant concentrations and associated human health risks (from the total PCB average surface sediment concentration estimates). This uncertainty is driven by: 1) exposure assumptions from the HHRA; and 2) assumptions used in the food web model such as uptake factors and future water concentrations. The predictions of resident seafood tissue contaminant concentrations and risks are nevertheless useful for comparing the alternatives to one another because the uncertainties are the same for all alternatives, and therefore all of the alternatives should be affected similarly.

As discussed in Sections 2.9.2 and 8.3.4, the configuration and depth of the navigation channel could be modified in the future. These potential modifications would affect the post-construction conditions of the alternatives by removing additional material (e.g., RMC that had been placed as part of remediation) or requiring additional slope stability in areas where contaminated sediment is left behind (e.g., the toe of a cap bordering the navigation channel). This uncertainty is mitigated through the design and permitting process, which will require that any potential navigation modifications would not reduce the environmental protectiveness of the remedy in the EW, and that EPA is consulted during the permitting process.

9.16 Managing COCs Other than Risk Drivers

In addition to the risk drivers assessed, additional COCs were identified in both the human health and ecological risk assessments (Table 3-14) (Windward 2012a, 2012b). As summarized in Section 3, COCs were defined as detected contaminants with HQs greater than 1 (for both risk assessments) or excess cancer risk estimates greater than 1×10^{-6} (for human health). The risks associated with these other COCs were very small compared to the risks associated with the risk drivers. In addition, other COCs that are not risk drivers are always co-located with risk drivers and are therefore addressed in the remedial footprints (see Section 6.2.1). This section evaluates how concentrations of these other COCs would change following implementation of the various alternatives and how these changes would achieve risk reduction.

9.16.1 Human Health

Three risk drivers were identified based on the seafood consumption scenarios in the HHRA (total PCBs, cPAHs, and dioxins/furans), and one risk driver was identified based on the direct sediment contact scenarios (arsenic). Additionally, the following summarizes the COCs not identified as risk drivers for the HHRA:[146]

- **Seafood consumption** – arsenic, cadmium, PCP, alpha-BHC, dieldrin, total chlordane, heptachlor epoxide, and mirex
- **Direct sediment contact** – cPAHs, total PCBs, and total TEQ[147]

These COCs were not designated as risk drivers because of their limited contribution to overall risk and because of uncertainties associated with the risk estimates for these contaminants (see Section 3). Table 9-19 summarizes the risks associated with these COCs and the expected management of these risks through sediment remediation. In general, these contaminants are not expected to pose significant residual human health risks after remediation of EW sediments primarily because of the following reasons:

1. Baseline concentrations are similar to background (arsenic).
2. Low magnitude of threshold exceedance (cadmium); cadmium concentrations above SQS will be addressed by remedial action.
3. Low detection frequencies in tissue (pentachlorophenol detected in two clam tissue samples, alpha-BHC detected in two rockfish samples and one geoduck sample, and heptachlor epoxide detected in one rockfish and one crab sample).
4. They were never detected in sediment (alpha-BHC, heptachlor epoxide, mirex, and dieldrin) or rarely detected in sediment (total chlordane detected in one sample and PCP detected in eight sediment samples).
5. Risks for direct sediment contact scenarios are within EPA's target risk range, and site-wide sediment concentrations are predicted to decrease by a factor of 2 to 9 following remediation (total PCBs and total TEQ). Clamming area sediment concentrations are also expected to decrease based on remediation of these areas (e.g., by a factor of 10 to 14 for the alternatives for cPAHs).

Details regarding this rationale are presented in Table 9-19, and these non-risk driver COCs are discussed further in Section A.7 of the baseline HHRA (Windward 2012b).

[146] No COCs or risk drivers were identified based on exposure to surface water.

[147] Total TEQ is equal to the sum of PCB TEQ and dioxin/furan TEQ.

Table 9-19

Remaining Human Health COCs for Consideration in FS and Expected Risk Outcomes

Human Health COC	Risk Estimate	Additional Considerations	Conclusion
Seafood Consumption Scenarios			
Arsenic	2×10^{-4} [a]	EW sediment concentrations were similar to or lower than those in samples collected from background areas in Puget Sound (see Section B.5.5.1.2 of the HHRA [Windward 2012b]).	Baseline concentrations are within background range.
Cadmium	HQ = 2[b]	There is considerable uncertainty associated with the consumption rates for the child tribal scenario and the HQ is more than an order of magnitude lower than that for total PCBs (HQ of 58); Cadmium HQs for the other two RME scenarios are less than 1; EW sediment SWAC (0.66 mg/kg dw) less than the 90^{th} percentile PSAMP rural Puget Sound concentration (0.73 mg/kg dw)	Baseline concentrations are within background range; low magnitude of threshold exceedance; tissue concentrations may decrease following remediation
Pentachlorophenol	2×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk, low detection frequency in EW tissue samples (detected in two clam tissue samples), and low detection frequency in sediment (4.6%).	Baseline risk is already within EPA's Target Risk Range
alpha-BHC	4×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk and low detection frequency in EW tissue samples (17%) and never detected in sediment.	Baseline risk is already within EPA's Target Risk Range.
Dieldrin	8×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk and detected in less than half of EW tissue samples (two rockfish and one geoduck sample) and never detected in sediment.	Baseline risk is already within EPA's Target Risk Range.
Total chlordane	2×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk and never detected in sediment.	Baseline risk is already within EPA's Target Risk Range.
Heptachlor epoxide	2×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk and low detection frequency in EW tissue samples (one rockfish sample and one crab sample) and never detected in sediment.	Baseline risk is already within EPA's Target Risk Range.
Mirex	4×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk and detected in less than half of EW tissue samples (detection frequency is 43%) and never detected in sediment.	Baseline risk is already within EPA's Target Risk Range.

Table 9-19

Remaining Human Health COCs for Consideration in FS and Expected Risk Outcomes

Human Health COC	Risk Estimate	Additional Considerations	Conclusion
Direct Sediment Contact Scenarios			
Total PCBs	3×10^{-6} [c]	Contributes less than 10% of the total excess cancer risk. Based on Table 9-1, concentrations in sediment are predicted to decrease by a factor of 3 to 9 for PCBs (depending on the alternative), indicating that post-remedy risks should be below 1×10^{-6}. [d]	Baseline risk is already within EPA's Target Risk Range; post-remedy risk expected to be less than 1×10^{-6} for all alternatives based on predicted sediment concentrations.
Total TEQ	2×10^{-6} [c]	Contributes less than 10% of the total excess cancer risk. Based on Table 9-1, concentrations in sediment are predicted to decrease by a factor of 3 to 9 for PCBs and 2 to 3 for dioxins/furans (depending on the alternative), indicating that post-remedy risks should be below 1×10^{-6}. [d]	Baseline risk is already within EPA's Target Risk Range; post-remedy risk expected to be less than 1×10^{-6} for all alternatives based on predicted sediment concentrations.

Notes:

a. Risks shown are for the adult tribal RME seafood consumption scenario.
b. Non-cancer HQ is for the child tribal RME seafood consumption scenario.
c. Risks shown are for the tribal clamming RME scenario.
d. Risk reductions are based on predicted site-wide concentrations because predictions for the tribal clamming exposure areas (on which the risks in the HHRA were based) were not available.

BHC – benzene hexachloride
COC – contaminant of concern
EPA – Environmental Protection Agency
EW – East Waterway
HHRA – human health risk assessment
HQ – hazard quotient
PCB – polychlorinated biphenyl
PSAMP - Puget Sound Ambient Monitoring Program
RME – reasonable maximum exposure
SWAC – spatially-weighted average concentration
TEQ – toxic equivalent
TRV – toxicity reference value

9.16.2 Ecological Health

The risk drivers identified based on the ERA included the 29 COCs above the SQS (for benthic invertebrates), TBT (for benthic invertebrates), and total PCBs (for fish). Additionally, the following summarizes the COCs not identified as risk drivers for the ecological receptors:[148]

- **Benthic invertebrates** – total DDTs (based on DMMP) and naphthalene (based on one porewater result)
- **Crabs** – cadmium, copper, and zinc
- **Fish** – cadmium, copper, vanadium, and TBT

These COCs were not designated as risk drivers because of the high levels of uncertainties and/or the low LOAEL HQs. Table 9-20 summarizes the risks associated with these COCs and the expected management of these risks through sediment remediation. In general, these contaminants are not expected to pose significant residual ecological risks after remediation of EW sediments primarily because of the following reasons:

1. Total DDTs were detected in only eight sediment samples, which all contained total PCB concentrations above the RAL and are within the remedial footprint.
2. Naphthalene was identified as a COC based on one porewater result. The sediment in the vicinity of the porewater is within the remediation footprint. Sediment concentrations of naphthalene in this area are expected to be reduced following remediation.
3. Cadmium, copper, zinc, and TBT sediment PRGs have been developed for benthic invertebrates. Therefore, remediation will result in reduced concentrations of these contaminants.
4. Baseline concentrations are less than or similar to background (cadmium, copper, and vanadium).

Details regarding this rationale are presented in Table 9-20, and these non-risk driver COCs are discussed further in Section A.7 of the baseline ERA (Windward 2012a)

[148] No COCs or risk drivers were identified for wildlife (bird and mammal) ecological receptors.

Table 9-20
Remaining Ecological COCs for Consideration in FS and Expected Risk Outcomes

Ecological COC	Exposure Pathway	Maximum NOAEL-Based HQ	Maximum LOAEL-Based HQ	Additional Considerations[a]	Conclusion
Benthic Invertebrates					
Total DDTs	sediment	na	1.4	Uncertainty in exposure data (i.e., detection frequency of 5.6% in sediment); both of the sediment samples above the effects threshold contain PCBs above the RAL, and therefore the samples will be addressed by remediation.	Low magnitude of threshold exceedance; sediment concentrations may decrease following remediation
Naphthalene	pore-water	300	9	High uncertainty in effects data; only one porewater sample exceeded the LOEC and naphthalene did not exceed the SMS in any sediment samples. Area of porewater exceedance is within the remediation footprint.	Exceedance limited to a single sample; high level of uncertainty
Crabs					
Cadmium	tissue residue	6.0	1.4	Uncertainty associated with effects data; maximum exceedance of LOAEL is less than 2; EW sediment SWAC (0.66 mg/kg dw) less than the 90th percentile PSAMP rural Puget Sound concentration (0.73 mg/kg dw). Sediment concentrations above the SMS will be remediated, resulting in reduction in cadmium concentrations.	Baseline concentrations are within background range
Copper	tissue residue	11	1.1	Uncertainty associated with effects data; maximum exceedance of LOAEL is less than 2; EW sediment SWAC (62 mg/kg dw) similar to the 90th percentile PSAMP rural Puget Sound concentration (50 mg/kg dw). Sediment concentrations above the SMS will be remediated, resulting in reduction in copper concentrations.	Baseline concentrations are within background range
Zinc	tissue residue	4.2	1.5	Uncertainty associated with effects data; maximum exceedance of LOAEL is less than 2. Sediment concentrations above the SMS will be remediated, resulting in reduction in zinc concentrations.	low magnitude of threshold exceedance; tissue concentrations may decrease following remediation
Fish					
Cadmium	dietary	13	2.5	High uncertainty in effects data; EW sediment SWAC (0.66 mg/kg dw) less than the 90th percentile PSAMP rural Puget Sound concentration (0.73 mg/kg dw).	Baseline concentrations are within background range

Table 9-20
Remaining Ecological COCs for Consideration in FS and Expected Risk Outcomes

Ecological COC	Exposure Pathway	Maximum NOAEL-Based HQ	Maximum LOAEL-Based HQ	Additional Considerations[a]	Conclusion
Copper	dietary	2.2	1.1	Medium uncertainty in effects data; exceedance of LOAEL is low; EW sediment SWAC (62 mg/kg dw) similar to the 90th percentile PSAMP rural Puget Sound concentration (50 mg/kg dw).	Baseline concentrations are within background range
Vanadium	dietary	9.5	1.9	High uncertainty in effects data; EW sediment SWAC (65.7 mg/kg dw) was less than the 90th percentile PSAMP rural Puget Sound concentration (64 mg/kg dw).	Baseline concentrations are within background range
TBT	tissue residue	14	1.4	High uncertainty in effects data; 3 of 13 individual rockfish concentrations exceeded the LOAEL (overall sitewide EPC did not exceed LOAEL). Sediment PRG developed for benthic invertebrates has been used to identify the remedial footprint. TBT sediment concentrations following remediation will be reduced.	Low magnitude of threshold exceedance; tissue concentrations may decrease following remediation

Notes:

a. More details are provided in Table A.7-1 (for benthic invertebrates and crabs) and in Table A.7-2 (for fish) of the ERA (Windward 2012a).

COC – contaminant of concern
DDT – dichlorodiphenyltrichloroethane
ERA – ecological risk assessment
EW – East Waterway
FS – feasibility study
HQ – hazard quotient
LOAEL – lowest-observed-adverse-effect level
LOEC – lowest-observed-effect concentration
NOAEL – no-observed-adverse-effect level
PCB –polychlorinated biphenyl
PRG – preliminary remediation goal
PSAMP – Puget Sound Ambient Monitoring Program
RAL – remedial action level
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SWAC – spatially-weighted average concentration
TBT – tributyltin
TRV – toxicity reference value

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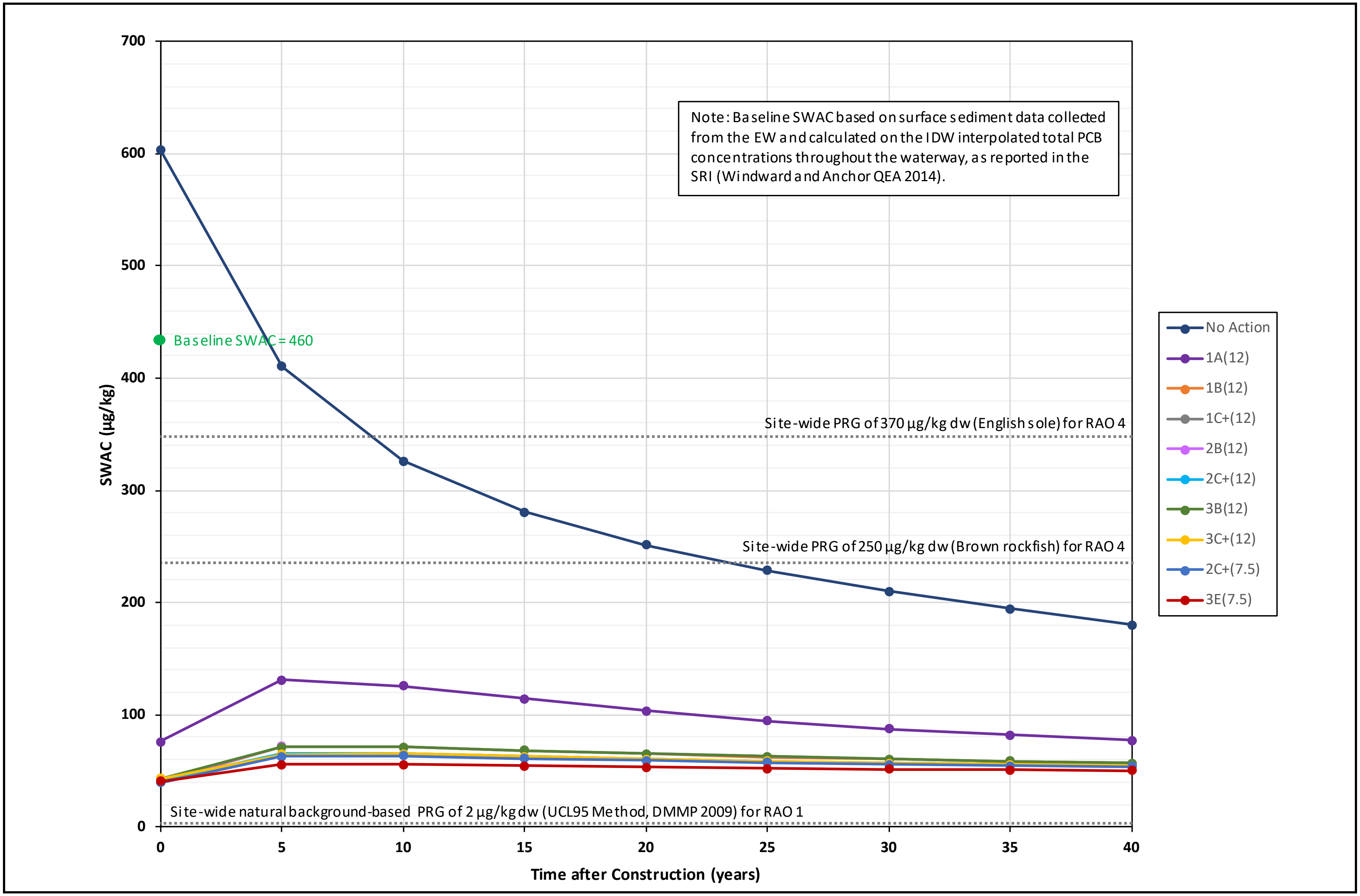
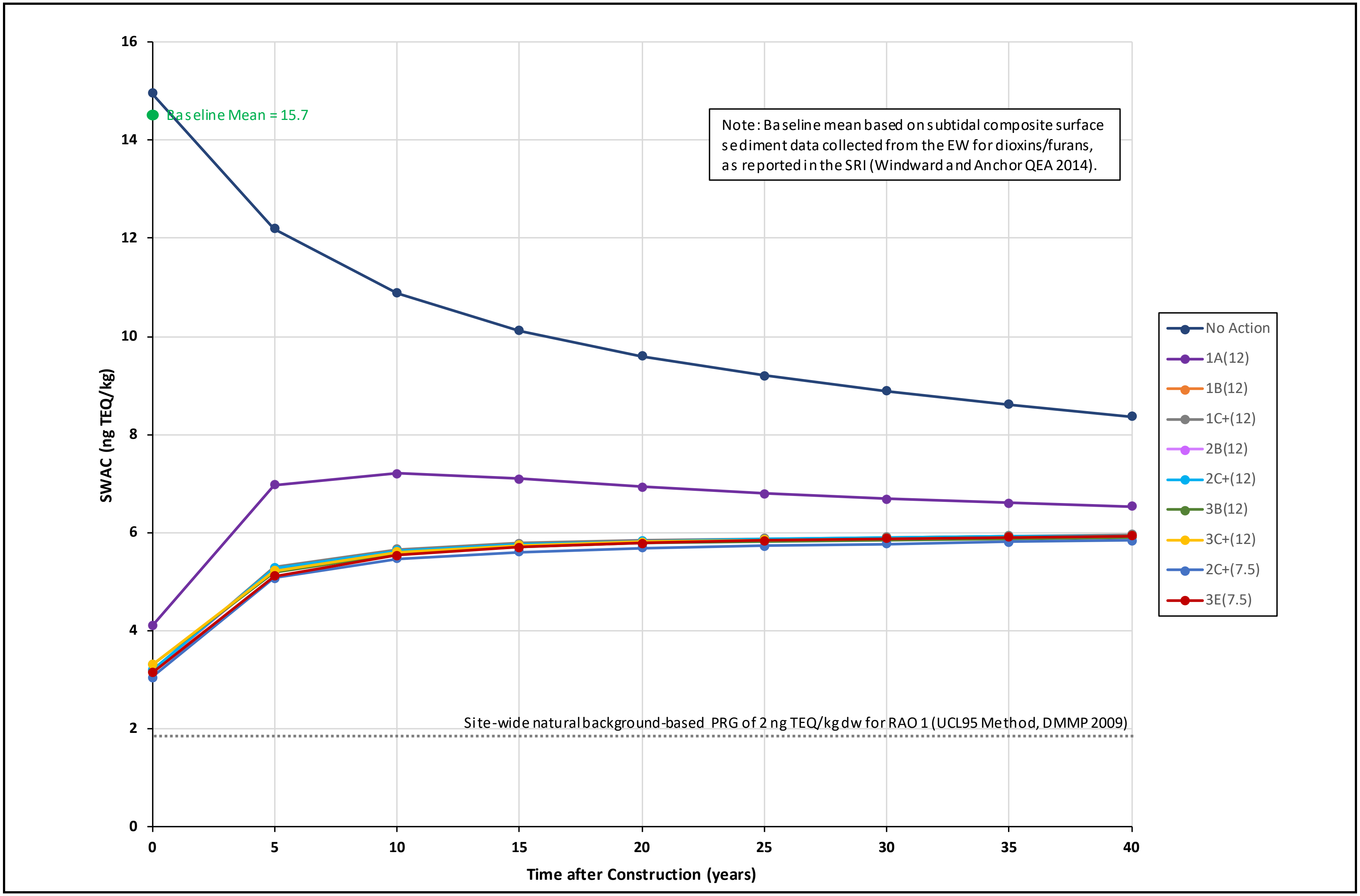


µg/kg = microgram per kilogram
dw = dry weight
IDW = inverse distance weighting
PCB = polychlorinated biphenyl
RAO = remedial action objective
SRI = Supplemental Remedial Investigation
SWAC = spatially-weighted average concentration
PRG = preliminary remediation goal
UCL95 = 95% upper confidence limit on the mean

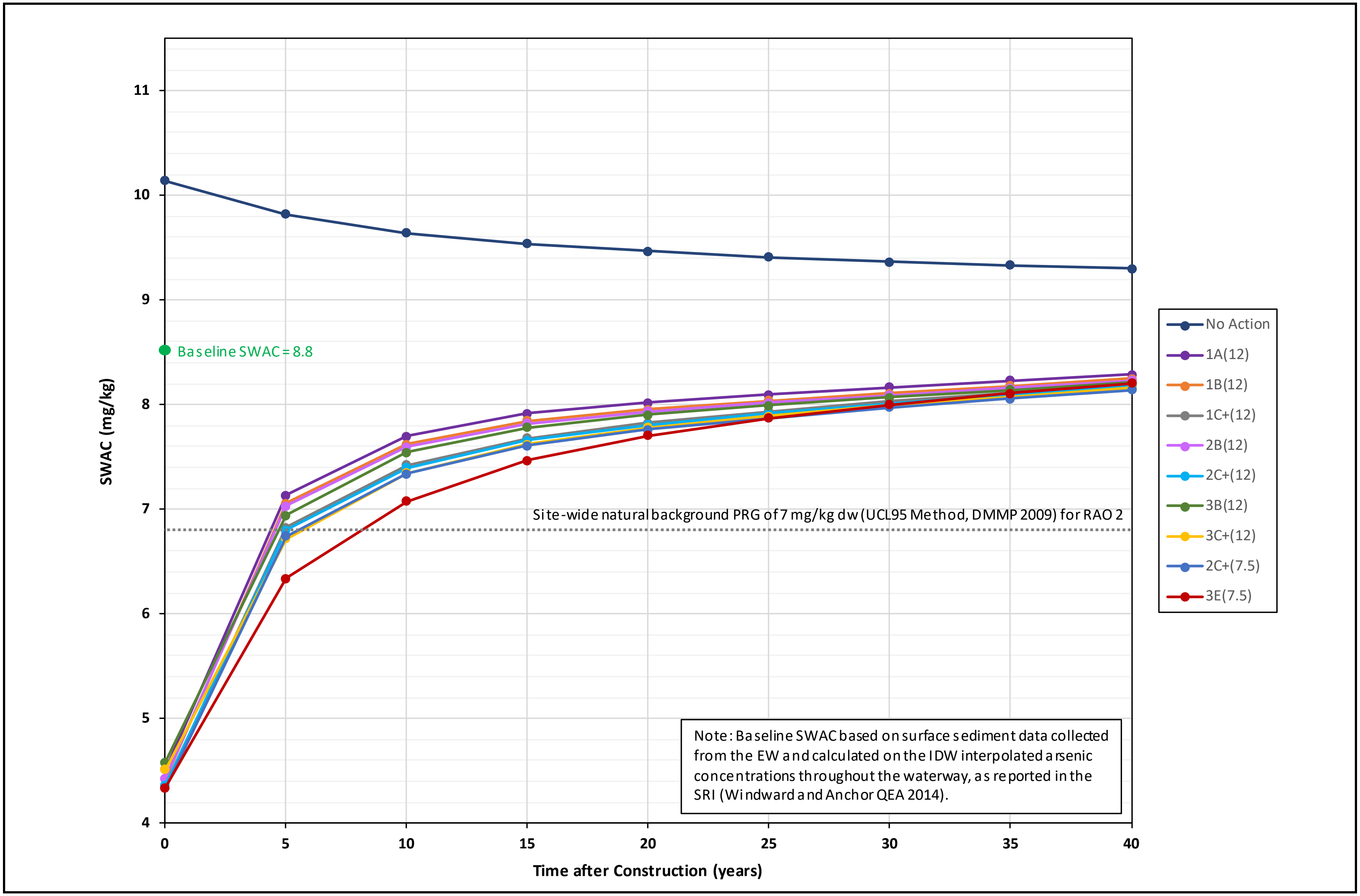
Figure 9-1a
Predicted Site-wide SWAC for Total PCBs Over Time
Feasibility Study
East Waterway Study Area



dw = dry weight
SRI = Supplemental Remedial Investigation
SWAC = spatially-weighted average concentration
PRG = preliminary remediation goal
RAO = remedial action objective

kg = kilogram
ng = nanogram
TEQ = toxic equivalent
UCL95 = 95% upper confidence limit on the mean

Figure 9-1b
Predicted Site-wide SWAC for Dioxins/Furans Over Time
Feasibility Study
East Waterway Study Area



dw = dry weight
mg/kg = milligram per kilogram
PRG = preliminary remediation goal
RAO = remedial action objective

SRI = Supplemental Remedial Investigation
SWAC = spatially-weighted average concentration
UCL95 = 95% upper confidence limit on the mean

Figure 9-1c
Predicted Site-wide SWAC for Arsenic Over Time
Feasibility Study
East Waterway Study Area

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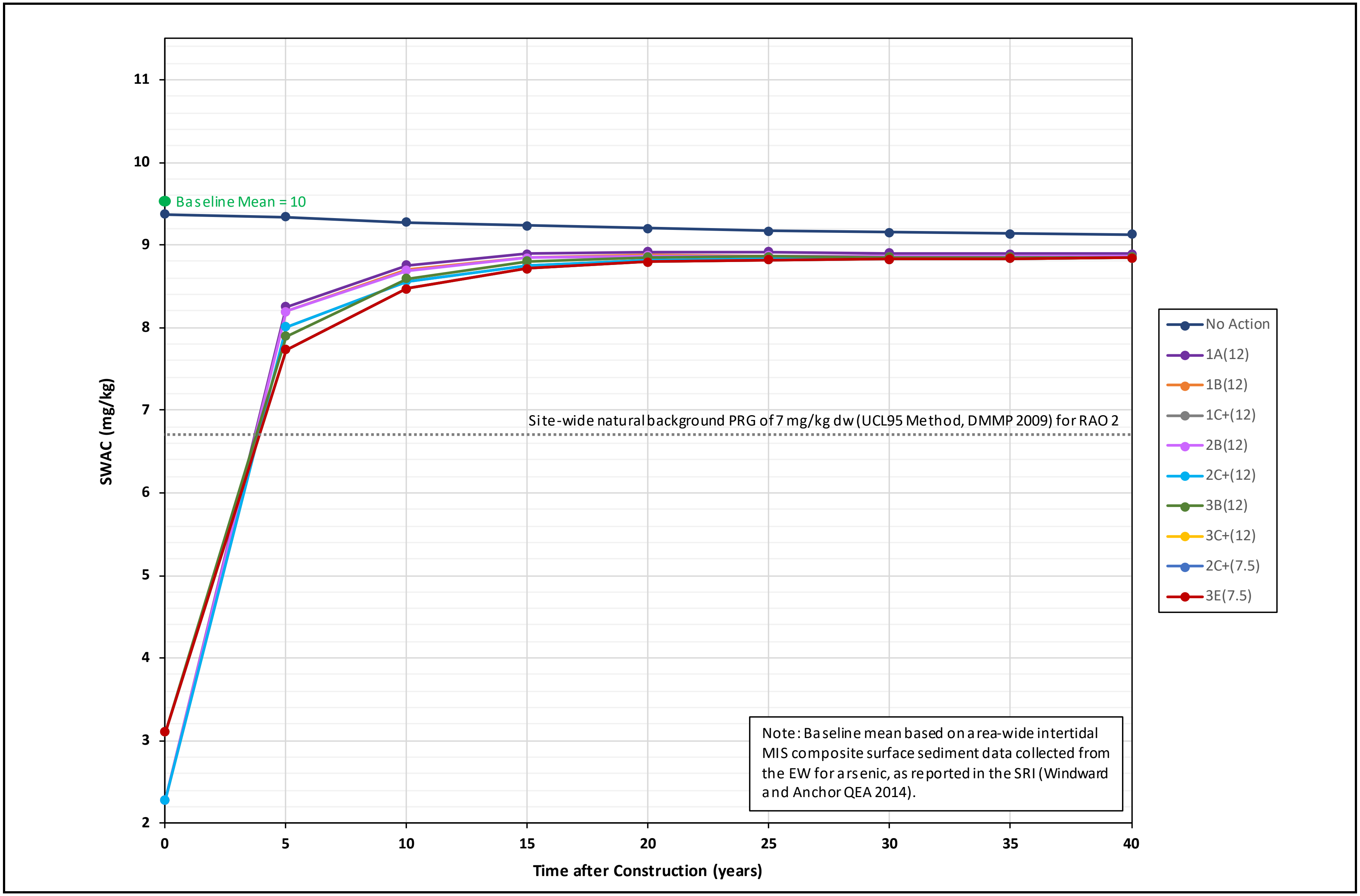
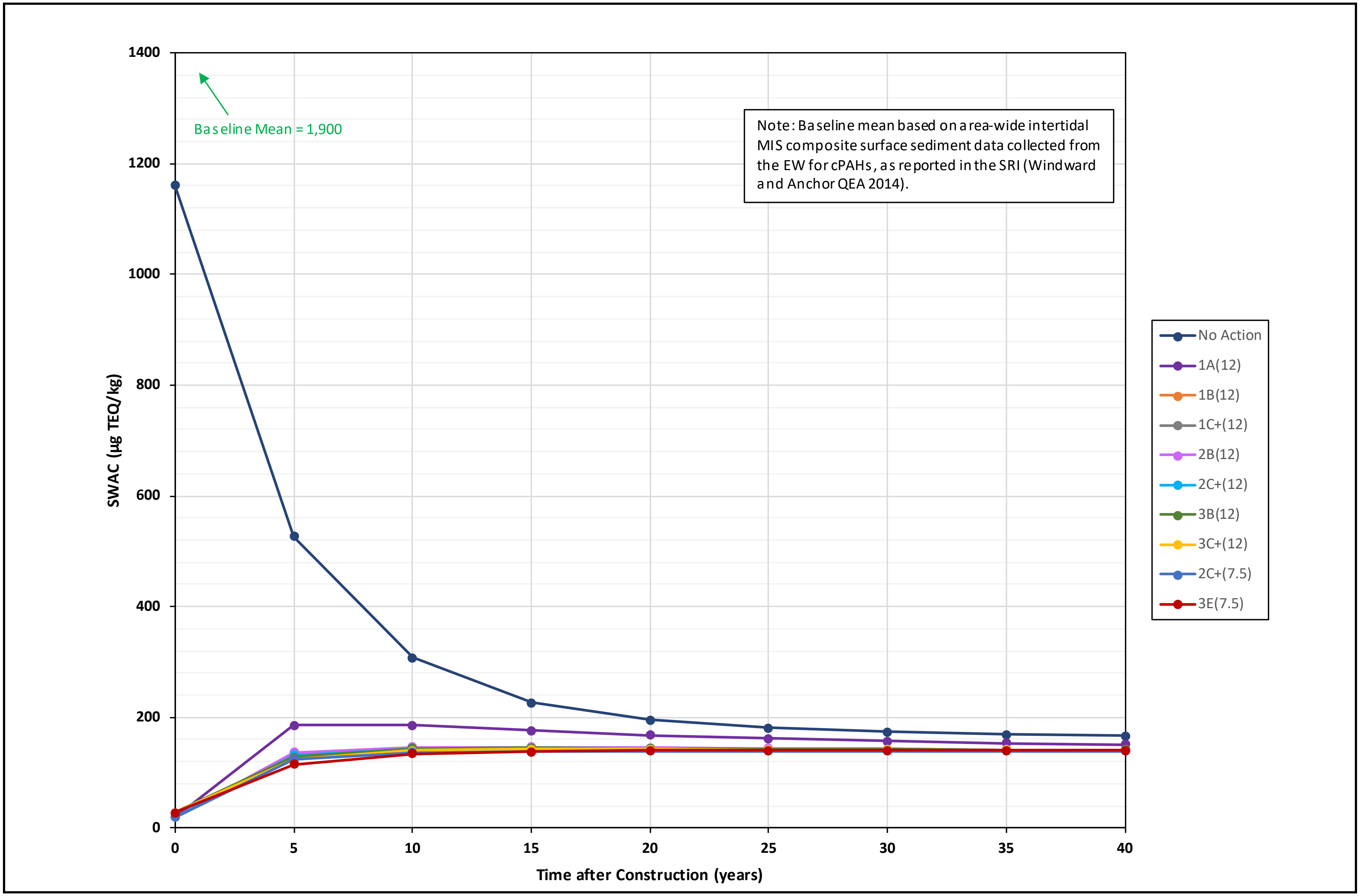


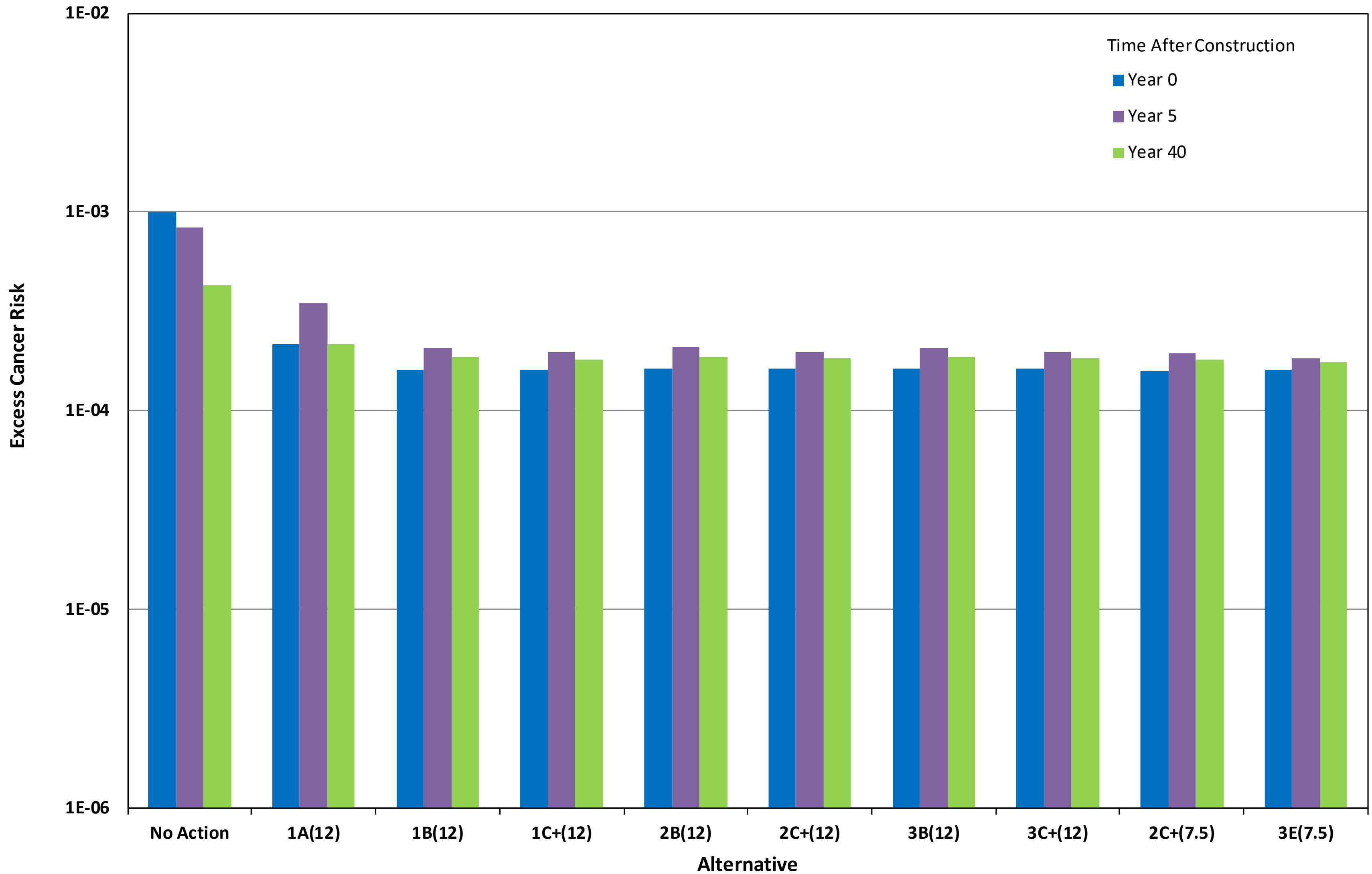
dw = dry weight
mg/kg = milligram per kilogram
PRG = preliminary remediation goal
RAO = remedial action objective
SRI = Supplemental Remedial Investigation
SWAC = spatially-weighted average concentration
UCL95 = 95% upper confidence limit on the mean

Figure 9-2a
Predicted Clamming Area SWAC for Arsenic Over Time
Feasibility Study
East Waterway Study Area



Notes:
SWACs are shown for informational purposes. cPAHs are a risk-driver COC for RAO 1 for consumption of clams; however, a PRG was not developed because the clam tissue-to-sediment relationship for cPAHs in the EW is too uncertain to develop a sediment RBTC based on clam consumption (see Section 3.3.4).
µg = microgram
cPAH = carcinogenic polycyclic aromatic hydrocarbon
dw = dry weight
kg = kilogram
SRI = Supplemental Remedial Investigation
SWAC = spatially-weighted average concentration
TEQ = toxic equivalent

Figure 9-2b
Predicted Clamming Area SWAC for cPAHs Over Time
Feasibility Study
East Waterway Study Area



PCB = polychlorinated biphenyl; RME = reasonable maximum exposure

Figure 9-3a

Estimated Total PCB Excess Cancer Risks for the Adult Tribal RME Seafood Consumption Scenario
Feasibility Study
East Waterway Study Area

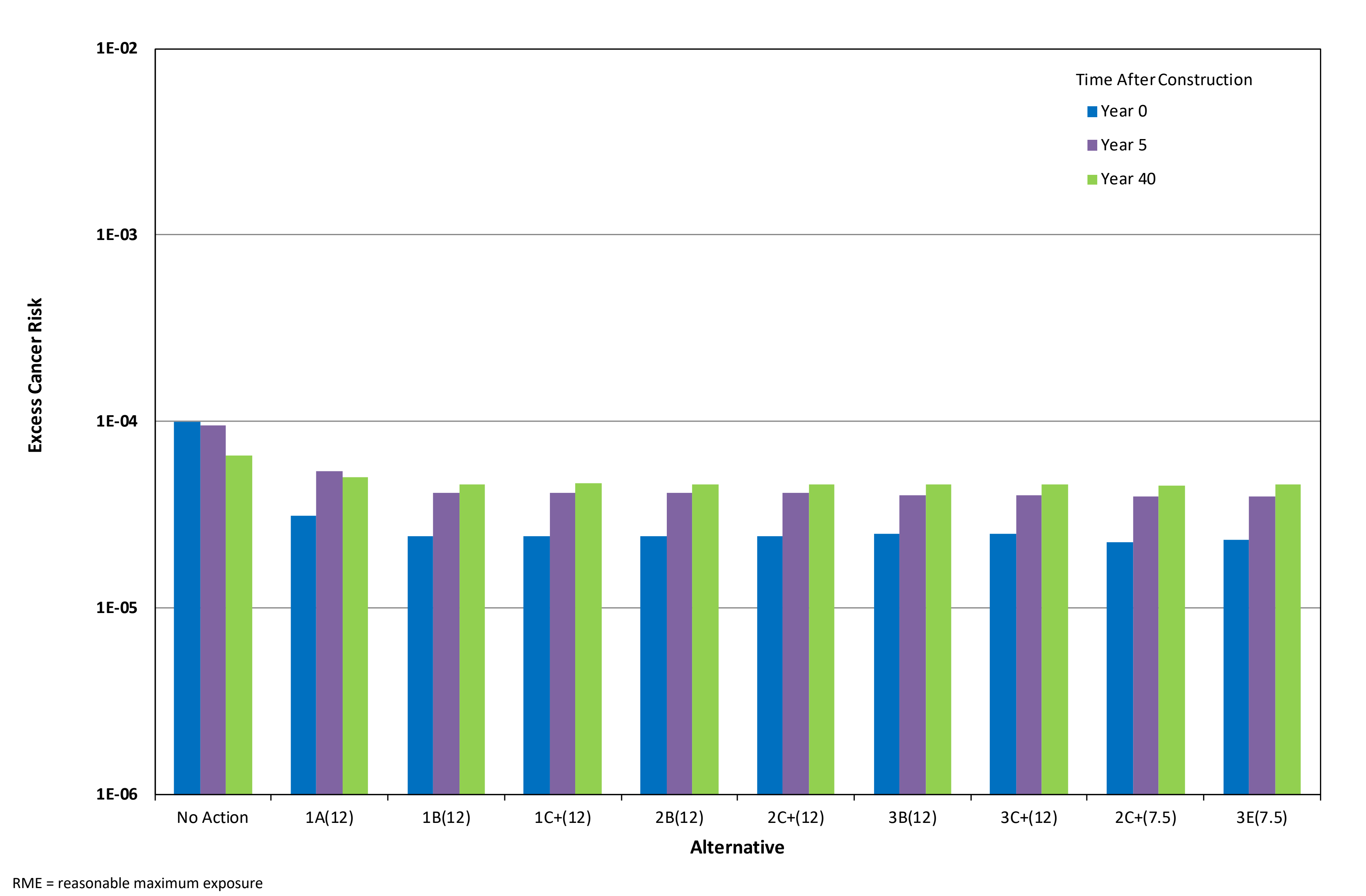


Figure 9-3b
Estimated Dioxin/Furans Excess Cancer Risks for the Adult Tribal RME Seafood Consumption Scenario
Feasibility Study
East Waterway Study Area

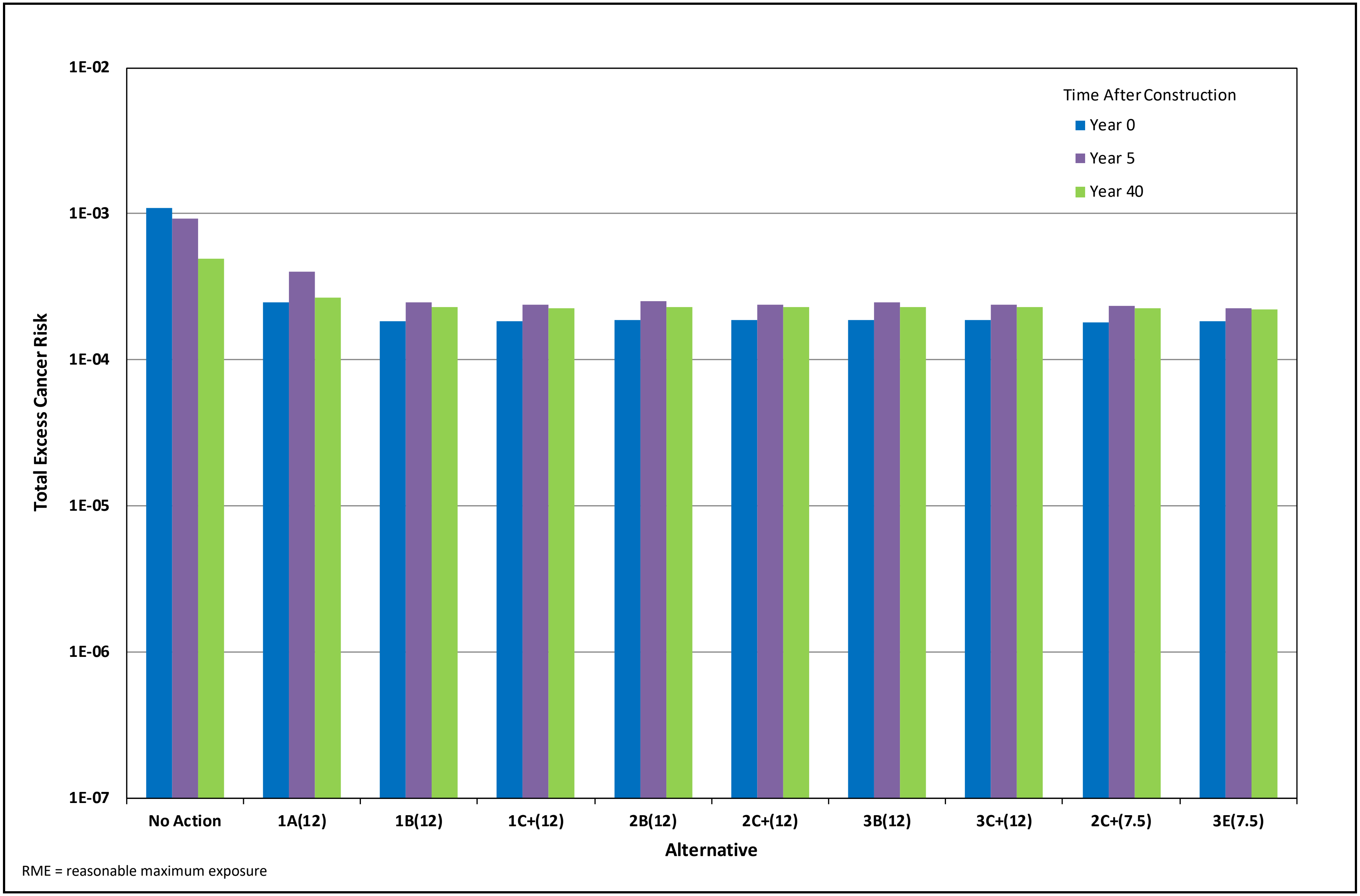


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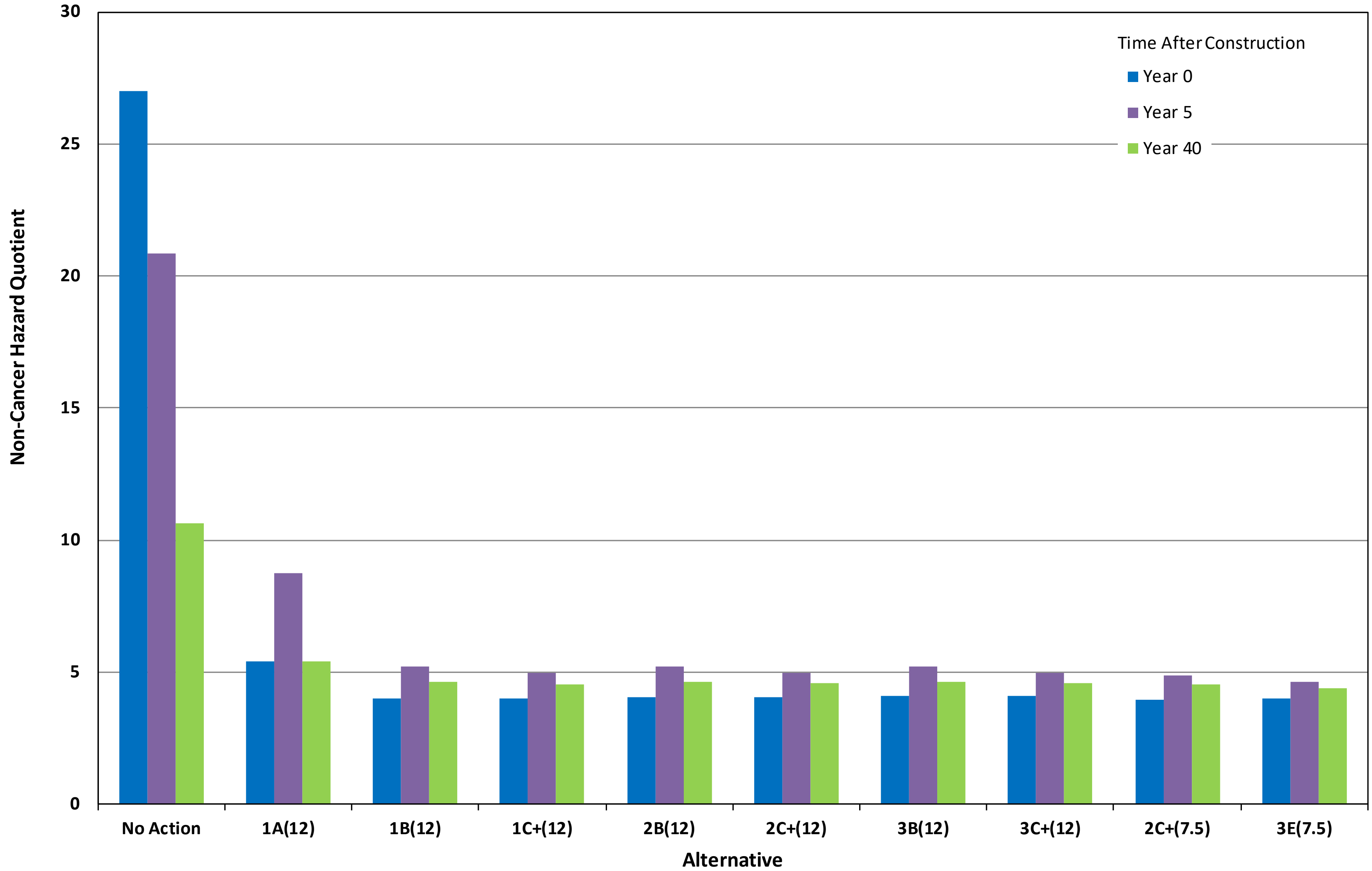
Figure 9-4
Total Excess Cancer Risks for the Adult Tribal RME Seafood Consumption Scenario
Feasibility Study
East Waterway Study Area



Note: Total PCBs non-cancer hazard quotients based on the immunological, integumantary, or neurological endpoints.

PCB = polychlorinated biphenyl; RME = reasonable maximum exposure

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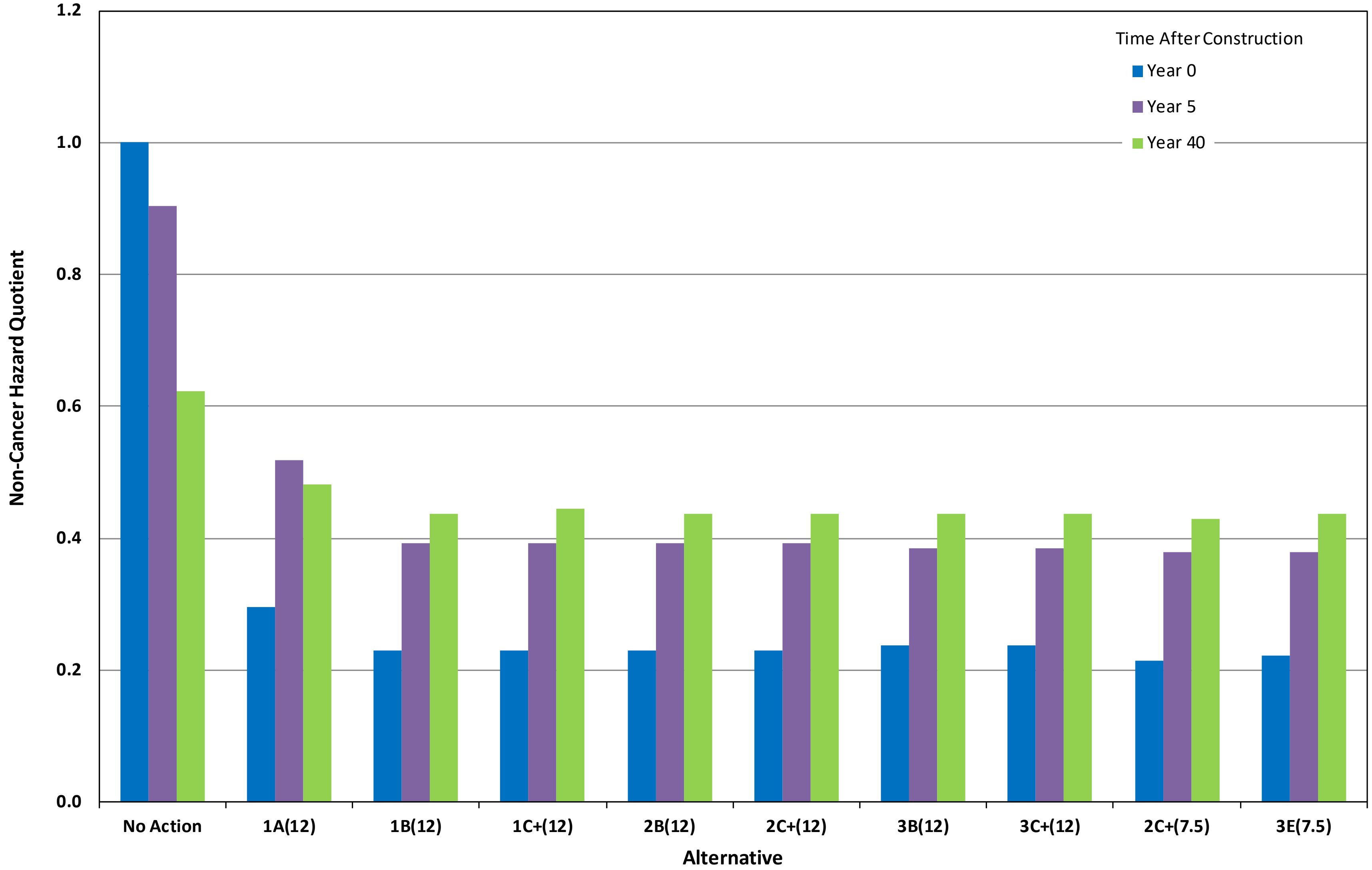
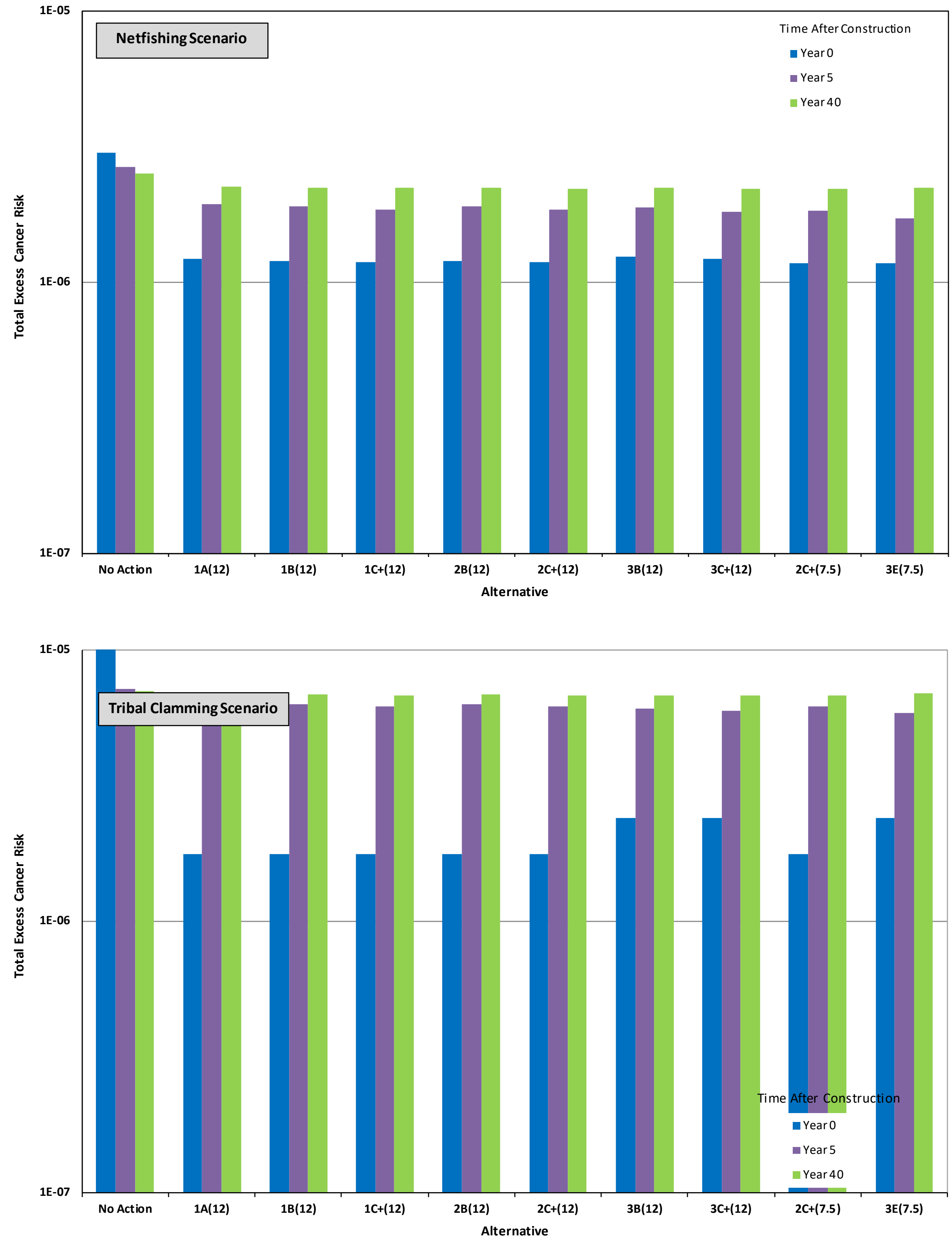
Figure 9-5a
Total PCB Non-cancer Hazard Quotients for the Adult Tribal RME Seafood Consumption Scenario
Feasibility Study
East Waterway Study Area



RME = reasonable maximum exposure

Figure 9-5b
Dioxin/Furans Non-cancer Hazard Quotients for the Adult Tribal RME Seafood Consumption Scenario
Feasibility Study
East Waterway Study Area



Note: Total direct contact excess cancer risks include arsenic risks for the netfishing scenario and the sum of arsenic and cPAHs risks for the tribal clamming scenario.

cPAH = carcinogenic polycyclic aromatic hydrocarbon
RME = reasonable maximum exposure

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Figure 9-6
Total Excess Cancer Risks for Netfishing and Tribal Clamming RME Scenarios
Feasibility Study
East Waterway Study Area

NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2015.
3. Outfalls shown are for storm drain basins unless otherwise noted.

Criteria used for Contaminants of Concern (COC) Exceedance:
1,4 DCB - 3.1 mg/kg-OC
BEHP - 47 mg/kg-OC
Dioxin/Furan - 25 ng TEQ/kg dw
Mercury - 0.41 mg/kg dw

0 500 1,000
Scale in Feet

Figure 9-7a
Exceedances in PTM Model - Years 0 to 10
Feasibility Study
East Waterway Study Area

NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2015.
3. Outfalls shown are for storm drain basins unless otherwise noted.

Criteria used for Contaminants of Concern (COC) Exceedance:
1,4 DCB - 3.1 mg/kg-OC
BEHP - 47 mg/kg-OC
Dioxin/Furan - 25 ng TEQ/kg dw
Mercury - 0.41 mg/kg dw

0 500 1,000
Scale in Feet

Figure 9-7b
Exceedances in PTM Model - Years 11 to 30
Feasibility Study
East Waterway Study Area

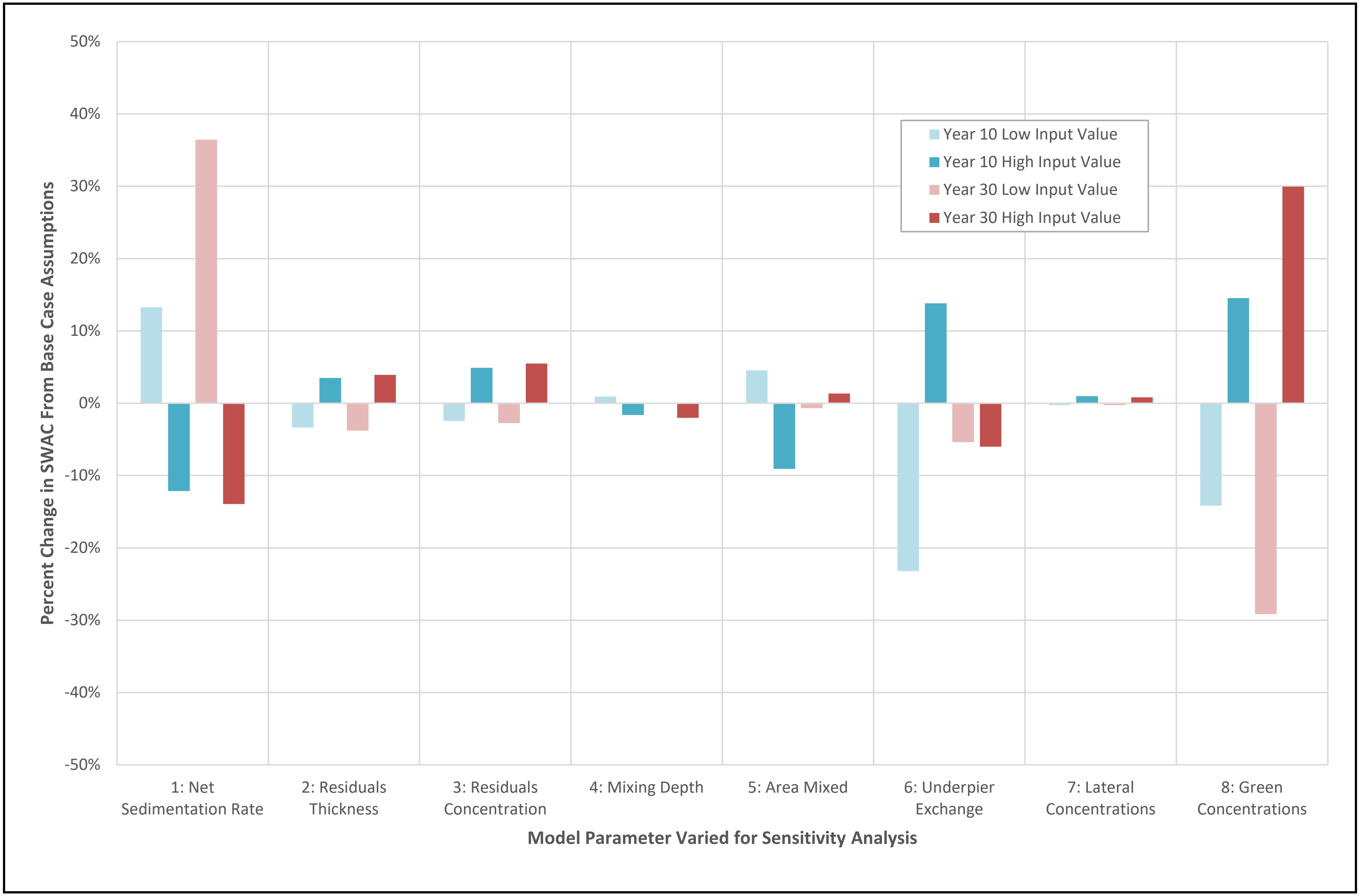

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Figure 9-8a
Sensitivity Analysis, Relative Change in SWAC Values Compared to Base Case, Alternative 1A(12)
Feasibility Study
East Waterway Study Area

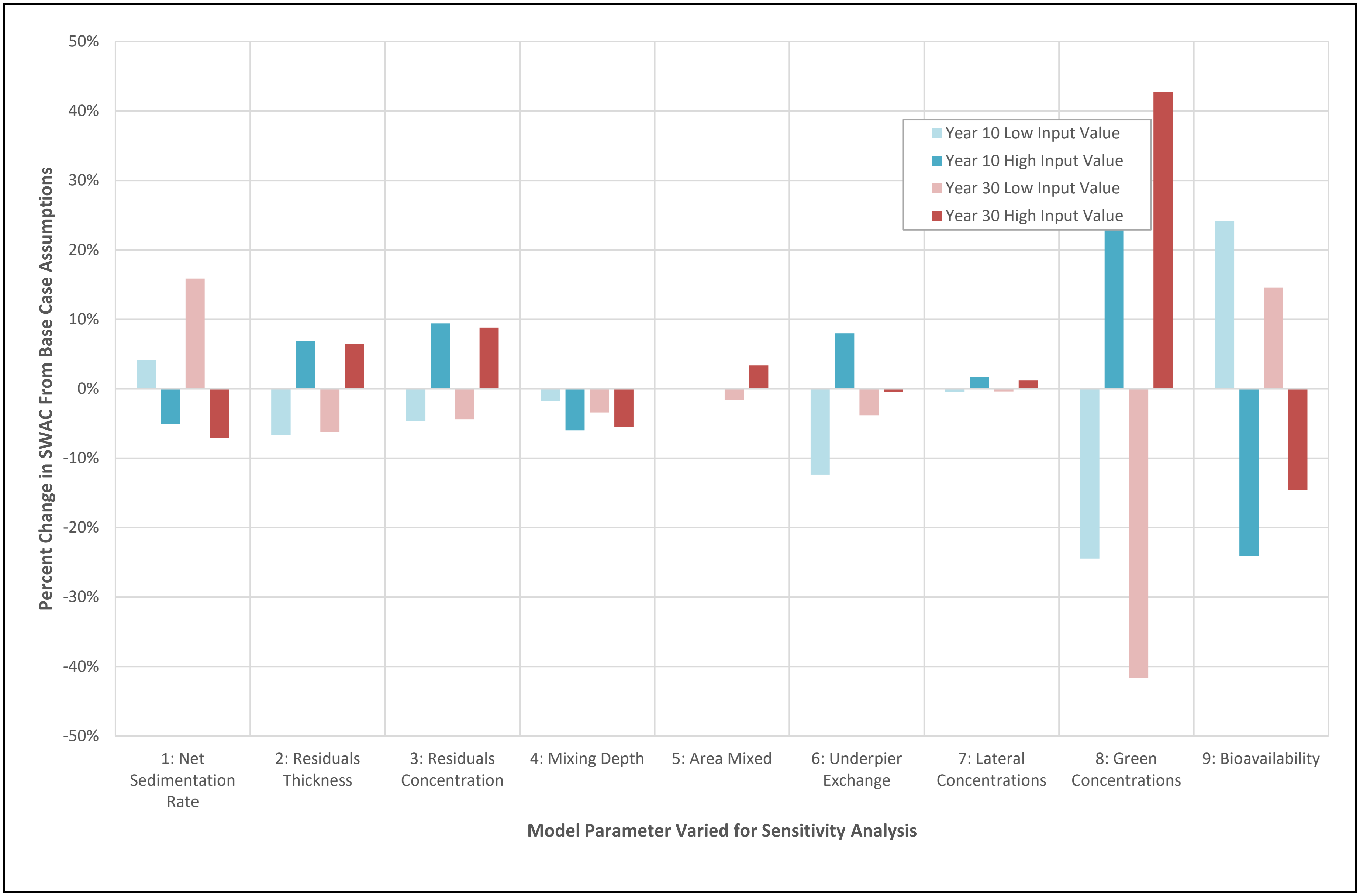

Figure 9-8b
Sensitivity Analysis, Relative Change in SWAC Values Compared to Base Case, Alternative 2B(12)
Feasibility Study
East Waterway Study Area

10 CERCLA COMPARATIVE ANALYSIS

This section performs the comparative evaluation of the alternatives based on CERCLA and the NCP, using the evaluation criteria presented in Section 9 to evaluate each alternative. Table 10-1 summarizes the comparative evaluation. The alternatives are first evaluated to assess whether they achieve or do not achieve the two threshold criteria. Then all remaining alternatives undergo detailed comparison using the five balancing criteria. The two modifying criteria will be evaluated later by EPA following public comment on its Proposed Plan. For the CERCLA balancing criteria, the table ranks the alternatives using a five-star ranking scale: one star (★) is the lowest rank and five stars (★★★★★) is the highest rank, relative to the other alternatives. The rationale for the star rankings are described in Table 10-1 and in Section 10.2 for each of the balancing criteria.

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

<table>
<tr><th colspan="4" rowspan="2">Evaluation Criteria</th><th colspan="10">Alternative</th></tr>
<tr><th>No Action</th><th>1A(12)</th><th>1B(12)</th><th>1C+(12)</th><th>2B(12)</th><th>2C+(12)</th><th>3B(12)</th><th>3C+(12)</th><th>2C+(7.5)</th><th>3E(7.5)</th></tr>
<tr><td colspan="14">Threshold Criteria</td></tr>
<tr><td colspan="14">Overall Protection of Human Health and the Environment</td></tr>
<tr><td rowspan="6">Long-term Effectiveness and Permanence</td><td rowspan="4">Magnitude and Type of Residual Risk</td><td>RAO 1 – Human Health (Seafood Consumption) [b, c]</td><td>Total PCBs and Dioxins/Furans</td><td>No Action is predicted to achieve total excess cancer risk of 5×10^{-4} (Adult Tribal RME), 9×10^{-5} (Child Tribal RME), and 2×10^{-4} (Adult API RME), and total PCB HQs of 11 (Adult Tribal RME), 23 (Child Tribal RME) and 9 (Adult API RME).</td><td colspan="9">The action alternatives are predicted to achieve total excess cancer risks of 2 to 3×10^{-4} (Adult Tribal RME), 4 to 5×10^{-5} (Child Tribal RME), and 1×10^{-4} to 9×10^{-5} (Adult API RME). The alternatives are also predicted to achieve total PCBs non-cancer risks (based on immunological, integumentary, or neurological endpoints only, which are the highest of the non-cancer risks) of HQ = 4 to 5 (Adult Tribal RME), HQ = 9 to 12 (Child Tribal RME), and HQ = 4 to 5 (Adult API RME).</td></tr>
<tr><td>RAO 2 – Human Health (Direct Contact)</td><td>Arsenic</td><td colspan="10">All alternatives are predicted to achieve a total excess cancer risk of less than 1×10^{-5}.For arsenic, all action alternatives achieve individual excess cancer risk of 2×10^{-6} for netfishing and 7×10^{-6} for clamming. Because the target risk threshold for arsenic is below natural background, the PRG is also used as a comparison: all action alternatives are predicted to meet the natural-background-based PRG following construction, but increase above the PRG in the long term due to incoming Green River concentrations. The No Action Alternative is not predicted to meet the arsenic PRG.</td></tr>
<tr><td>RAO 3 – Ecological Health (Benthic Organisms)</td><td>29 COCs [d]</td><td>Not expected to achieve.</td><td>Alternative 1A(12) is predicted to meet benthic PRGs in 99% of point locations 40 years following construction.</td><td colspan="8">Alternatives 1B(12) through 3E(7.5) are predicted to meet benthic PRGs in 100% of point locations after construction completion.</td></tr>
<tr><td>RAO 4 – Ecological Health (Fish)</td><td>Total PCBs</td><td>HQ > 1.0 using the lower LOAEL TRV; HQ ≤ 1.0 using the higher LOAEL TRV.</td><td colspan="9">All action alternatives are predicted to achieve HQ ≤ 1.0 for English sole and HQs ≤ 1.0 for brown rockfish for the higher TRV and 1.1 to 1.3 for the lower TRV (assumptions regarding water concentrations result in HQs slightly above 1.0) at year 40 following construction.</td></tr>
<tr><td rowspan="2">Controls</td><td colspan="2">Engineering Controls</td><td rowspan="2">No controls assumed.</td><td>Relies primarily on removal (77 acres). Some reliance on partial removal and capping (13 acres), ENR-nav/partial removal and ENR-nav (16 acres), ENR-sill (2 acres), and MNR (13 acres underpier and low bridges).</td><td>Same as Alternative 1A(12) but with in situ treatment in underpier areas (12 acres) and ENR-sill under low bridges (1 acre), instead of MNR.</td><td>Same as Alternative 1B(12) but with diver-assisted hydraulic dredging prior to in situ treatment in some underpier areas (2 acres).</td><td>More reliance on removal than Alternatives 1A(12), 1B(12), and 1C+(12) (94 acres). Some reliance on partial removal and capping (13 acres), ENR-sill (3 acres), and in situ treatment (12 acres) in underpier areas.</td><td>Same as Alternative 2B(12) but with diver-assisted hydraulic dredging prior to in situ treatment in some underpier areas (2 acres).</td><td>More reliance on removal than Alternatives 1A(12) through 2C+(12) (100 acres). Some reliance on partial removal and capping (7 acres), ENR-sill (1 acre), and in situ treatment in underpier areas (12 acres).</td><td>Same as Alternative 3B(12) but with diver-assisted hydraulic dredging prior to in situ treatment in some underpier areas (2 acres).</td><td>More reliance on removal due to a lower RAL of 7.5 mg/kg OC (104 acres). Some reliance on partial removal and capping (13 acres), ENR-sill (3 acres), and in situ treatment (11 acres) and diver-assisted hydraulic dredging followed by in situ treatment (2 acres) in underpier areas.</td><td>Most reliance on removal (111 acres). Some reliance on partial removal and capping (7 acres), ENR-sill (1 acre), and diver-assisted hydraulic dredging followed by in situ treatment in underpier areas (13 acres).</td></tr>
<tr><td colspan="2">Institutional Controls</td><td colspan="9">Institutional controls, including a notification, monitoring, and reporting program for areas of the EW and seafood consumption advisories and public outreach and education programs will be implemented to reduce seafood consumption exposures. Long-term monitoring, maintenance, and institutional controls are required for these alternatives.</td></tr>
<tr><td colspan="4">Short-term Effectiveness</td><td>No short-term impact because no actions assumed.</td><td colspan="9">Short-term impacts increase with the length of construction (which vary from 9 to 13 years for the alternatives) and the amount of removal (810,000 to 1,080,000 cy) among the action alternatives. Alternatives 1B(12) through 3E(7.5) achieve RAOs immediately after construction completion, but will occur in a later calendar year for alternatives requiring a longer construction timeframe. Alternative 1A(12) meets all RAOs 39 years from the start of construction. PRGs for RAO 1 are not predicted to be achieved by any alternative. The time to achieve RAO 1 is uncertain, but all active alternatives will reach similar risk levels, except Alternative 1A(12), which may have greater uncertainty associated with MNR. See details on Short-term Effectiveness under Balancing Criteria.</td></tr>
</table>

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

<table>
<tr><th colspan="2" rowspan="2">Evaluation Criteria</th><th colspan="10">Alternative</th></tr>
<tr><th>No Action</th><th>1A(12)</th><th>1B(12)</th><th>1C+(12)</th><th>2B(12)</th><th>2C+(12)</th><th>3B(12)</th><th>3C+(12)</th><th>2C+(7.5)</th><th>3E(7.5)</th></tr>
<tr><td colspan="2">Summary of Overall Protection of Human Health and the Environment</td><td>Does not provide adequate overall protection to human health and the environment.</td><td colspan="9">The action alternatives achieve overall protection of human health and the environment by relying primarily on removal of contaminated sediment from the EW. The action alternatives vary primarily in the remedial approach used to remediate sediment in underpier areas. All underpier technologies require engineering controls, including diver-assisted hydraulic dredging, which cannot completely remove sediment due to riprap, debris, and structural supports. All alternatives require institutional controls to fully achieve protectiveness. Longer construction periods and greater removal volumes result in proportionately greater short-term impacts.</td></tr>
<tr><td colspan="12">Compliance of ARARs</td></tr>
<tr><td rowspan="4">MTCA/SMS</td><td>Human Health – Seafood Consumption (RAO 1)</td><td>Not expected to comply.</td><td colspan="9">The action alternatives are not likely to meet all natural background-based PRGs. If EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs, EPA may adjust the cleanup level upward to the CSL, which could be attained in a reasonable restoration timeframe, consistent with the substantive requirements of SMS (see Sections 4.3.1 and 9.1.1.2), or waive the ARAR on the basis of technical impracticability in a future decision document (ROD Amendment or ESD).</td></tr>
<tr><td>Human Health – Direct Contact (RAO 2)</td><td>Predicted to comply within 20 years by achieving the SMS background level for arsenic.</td><td colspan="9">All action alternatives are expected to comply immediately following construction by achieving the SMS background level for arsenic.</td></tr>
<tr><td>Ecological Health – Benthic Organisms (RAO 3)</td><td>Not expected to comply.</td><td>Alternative 1A(12) is predicted to achieve RAO 3 PRGs 39 years from the start of construction.</td><td colspan="8">Alternatives 1B(12) through 3E(7.5) are predicted to achieve RAO 3 PRGs immediately following construction.</td></tr>
<tr><td>Ecological Health - Higher Trophic Level Species (RAO 4)</td><td>Predicted to comply within 10 years (English sole) to 25 years (brown rockfish).</td><td colspan="9">All action alternatives are predicted to comply by achieving the RAO 4 PRGs immediately following construction.</td></tr>
<tr><td colspan="2">Surface Water Quality Standards</td><td colspan="10">No active remedial measures are technically feasible or anticipated expressly for the water column, although significant water quality improvements are anticipated from sediment remediation and additional source control measures. It is not anticipated that any alternative can comply with all federal or state ambient water quality criteria or standards, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain (e.g., total PCBs and arsenic). If long-term monitoring data and trends indicate that water quality ARARs cannot be met, EPA may determine whether further remedial action could practicably achieve the ARAR. If EPA concludes that an ARAR cannot be practicably achieved, EPA may waive the ARAR on the basis of technical impracticability in a future decision document (ROD Amendment or ESD).</td></tr>
<tr><td colspan="2">Achieve Threshold Criteria?</td><td>No</td><td colspan="9">Yes; however, one or more ARAR waivers may be required.</td></tr>
</table>

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

Evaluation Criteria			No Action	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Balancing Criteria												
Long-term Effectiveness and Permanence												
Magnitude of Residual Risk	Long-term Risk Outcomes		Does not achieve all.	See the risk outcomes for Magnitude and Type of Residual Risk above. The action alternatives achieve similar risk outcomes, with Alternative 1A(12) slightly higher for some risks.								
	Areas (acres; of 157 acres in the EW)[e]	Removal (open-water)	NA	77	77	77	94	94	100	100	104	111
		Partial removal/cap	NA	13	13	13	13	13	7	7	13	7
		Partial removal and ENR-nav, and ENR-nav	NA	16	16	16	NA	NA	NA	NA	NA	NA
		ENR-sill	NA	2	3	3	3	3	1	1	3	1
		MNR	NA	13	NA	NA	NA	NA	NA	NA	NA	NA
		In situ treatment	NA	NA	12	10	12	10	12	10	11	NA
		Diver-assisted hydraulic dredging followed by in situ treatment (underpier areas)	NA	NA	NA	2	NA	2	NA	2	2	13
		No action (area with concentrations < RALs for the action alternatives)	157	36	36	36	36	36	36	36	25	25
	Post-construction number of core stations remaining > CSL (of 76 cores in the EW)[f]	Partial dredging and capping	76	8	8	8	8	8	5	5	8	5
		Partial removal and ENR-nav, and ENR-nav		0	0	0	Not used	Not used	Not used	Not used	Not used	Not used
		ENR-sill		1	1	1	1	1	0	0	1	0
		MNR		0	Not used	Not used	Not used	Not used	Not used	Not used	Not used	Not used
		In situ treatment		Not used	0	0	0	0	0	0	0	Not used
		No action		2	2	2	2	2	2	2	2	2
	Summary of residual risks (modeled long-term risks and remaining subsurface contaminated sediment)		Highest long-term risks; most contaminated sediment remaining on site.	Slightly higher long-term risks than all active alternatives, moderate contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, moderate contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, moderate contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.
Adequacy and Reliability of Controls	Area requiring monitoring and maintenance (acres)	Moderate level of effort (partial dredging and capping)	No controls assumed.	13	13	13	13	13	7	7	13	7
		Higher level of effort (partial removal and ENR-nav, ENR-nav, ENR-sill, MNR, in situ treatment)		31	31	29	15	13	13	11	14	1
	Institutional Controls			The action alternatives require an Institutional Control Implementation and Assurance Plan with: 1) seafood consumption advisories, public outreach, and education programs; 2) review of in-water construction permit applications, waterway uses, and notification of users; and 3) designation of RNAs and other forms of notification and controls for areas with residual contamination to ensure performance of the remedy.								
Long-term Effectiveness and Permanence Ranking Guide			*The alternatives are ranked relative to other alternatives, with five stars representing the most effective in the long term and most permanent, and one star representing the least effective in the long term and least permanent. The ranking considers the metrics above, summarized as the following two that are considered equally: 1) the magnitude and type of residual risk remaining in the long term, including the risk outcomes and the area with remaining subsurface contamination; and 2) adequacy and reliability of engineering controls, considering the area requiring monitoring and maintenance.*									

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

Evaluation Criteria	Alternative									
	No Action	**1A(12)**	**1B(12)**	**1C+(12)**	**2B(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**2C+(7.5)**	**3E(7.5)**
Summary of Long-term Effectiveness and Permanence	*Least effective and permanent compared to the other alternatives.*	*1A(12) achieves similar risk as all action alternatives In open water areas, 1A(12) relies primarily on removal and also includes partial removal and capping, partial removal and ENR, and ENR. Underpier, 1A(12) relies on MNR. 1A(12) has less reliable underpier controls and open-water controls, compared to the other alternatives.*	*1A(12) achieves similar risk as all action alternatives In open water areas, 1B(12) is the same as 1A(12). Underpier, 1B(12) relies on in situ treatment. 1B(12) has more reliable underpier controls than 1A(12) and slightly less reliable open-water controls than 2B(12) through 3E(7.5)*	*1A(12) achieves similar risk as all action alternatives In open water areas, 1C+(12) is the same as 1A(12). Underpier, 1C+(12) relies on limited removal plus in situ treatment 1C+(12), has similarly reliable underpier controls as 1B(12), and slightly less reliable open-water controls than 2B(12) through 3E(7.5).*	*1A(12) achieves similar risk as all action alternatives In open water areas, 2B(12) is similar to 1A(12) but with no partial removal and ENR-nav or ENR-nav(more removal). Underpier, 2B(12) relies on in situ treatment. By relying almost exclusively on removal and capping, 2B(12) is considered highly permanent.*	*1A(12) achieves similar risk as all action alternatives In open water areas, 2C+(12) is the same as 2B(12). Underpier, 2C+(12) relies on limited removal plus in situ treatment By relying almost exclusively on removal and capping, 2C+(12) is considered highly permanent.*	*1A(12) achieves similar risk as all action alternatives In open-water areas, 3B(12) is similar to 2B(12) but with capping (more removal) Underpier, 2B(12) relies on in situ treatment. By relying almost exclusively on removal and capping, 3B(12) is considered highly permanent.*	*1A(12) achieves similar risk as all action alternatives In open water areas, 3C+(12) is the same as 3B(12). Underpier, 3C+(12) relies on limited removal plus in situ treatment By relying almost exclusively on removal and capping, 3C+(12) is considered highly permanent.*	*1A(12) achieves similar risk as all action alternatives In open water areas, 2C+(7.5) is the same as 2B(12) but with a slightly smaller no action area (more removal). Underpier, 2C+(7.5) relies on limited removal plus in situ treatment 2C+(7.5) is considered similarly permanent to 2C+(12) because the lower RAL remediates areas of low contaminant concentrations.*	*1A(12) achieves similar risk as all action alternatives In open water areas, 3E(7.5)+(7.5) is the same as 3B(12) but with a slightly smaller no action area (more removal). Underpier, 3E(7.5) relies on removal plus in situ treatment 3E(7.5) is considered similarly permanent to 2C+(7.5) because diver-assisted hydraulic dredging cannot remove all contaminated sediment on underpier structured slopes.*
Ranking [a] for long-term effectiveness and permanence	★	★★★	★★★★	★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
Reduction of Toxicity, Mobility, or Volume Through Treatment										
In situ treatment area (acres)	NA	NA	12	12	12	12	12	12	13	13
Summary of Reduction of Toxicity, Mobility, or Volume Through Treatment	*No treatment.*	*No treatment.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*
Reduction of Toxicity, Mobility, or Volume Through Treatment Ranking Guide	*The alternatives are ranked relative to the total remediation area in the waterway, with five stars representing the use of extensive in situ treatment among the alternatives, and one star representing no use of in situ treatment. Although none of the alternatives employ in situ treatment extensively in the waterway, the highest-ranked alternative is given five stars.*									
Ranking [a] for reduction of toxicity, mobility, or volume through treatment	★	★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

Evaluation Criteria				Alternative									
				No Action	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Short-term Effectiveness													
Protection of Human Health and the Environment During Construction	Period of effects to human health and the environment (construction timeframe; years) [g]			NA	9	9	9	10	10	10	10	11	13
	Transportation impacts (train/truck/barge; 1,000 miles)			NA	72 / 126 / 13	76 / 126 / 13	77 / 126 / 13	84 / 122 / 13	85 / 122 / 13	89 / 115 / 13	89 / 114 / 13	94 / 126 / 14	100 / 118 / 14
	Diver-assisted dredging (hazardous work duration; diver years)			NA	NA	NA	2	NA	2	NA	2	2	12
	Habitat area shallower than -10 feet MLLW impacted by dredging or capping in open-water areas (acres)			NA	4.1	4.1	4.1	4.1	4.1	5.8	5.8	4.7	6.6
	Depleted natural resources (material placement volume; cy)			NA	290,000	290,000	290,000	280,000	280,000	270,000	270,000	290,000	270,000
	Total removal volume / Consumed landfill capacity (cy) [h]			NA	810,000 / 970,000	810,000 / 970,000	820,000 / 980,000	900,000 / 1,080,000	910,000 / 1,090,000	960,000 / 1,150,000	960,000 / 1,150,000	1,010,000 / 1,210,000	1,080,000 / 1,300,000
	Air quality impacts (CO_2 / PM_{10} emissions; metric tons)			NA	16,000 / 5.4	16,000 / 5.6	16,000 / 5.9	17,000 / 6.1	18,000 / 6.3	18,000 /6.4	18,000 / 6.6	19,000 / 7.0	23,000 / 8.3
	Energy consumption (MJ)			NA	1.1×10^8	1.2×10^8	1.2×10^8	1.2×10^8	1.2×10^8	1.3×10^8	1.3×10^8	1.3×10^8	1.4×10^8
	Carbon footprint (acre-years)[i]			NA	3,800	3,800	3,800	4,000	4,300	4,300	4,300	4,500	5,400
Time to Achieve RAOs (Years from the Start of Construction)[j]	RAO 1 [k]	Total PCBs	10^{-4} Cancer Risk for Adult Tribal RME	35	9	9	9	10	10	10	10	11	13
			10^{-5} Cancer Risk for Child Tribal RME	Does not achieve.	34	9	9	10	10	10	10	11	13
			10^{-4} Cancer Risk for Adult API RME	0 (achieves at baseline conditions or start of construction)									
			10^{-5} Cancer Risk for Adult API RME	Does not achieve.	Not predicted to achieve.								
			Natural background PRG	Does not achieve.	Not predicted to achieve.								
		Dioxins/ Furans	10^{-4} Cancer Risk for Adult Tribal RME	0 (achieves at baseline conditions or start of construction)									
			10^{-5} Cancer Risk for Child Tribal RME	0 (achieves at baseline conditions or start of construction)									
			10^{-4} Cancer Risk for Adult API RME	0 (achieves at baseline conditions or start of construction)									
			10^{-5} Cancer Risk for Adult API RME	0 (achieves at baseline conditions or start of construction)									
			Natural background-based PRGs	Does not achieve.	Not predicted to achieve.								
	RAO 2[l]	Arsenic	Netfishing (site-wide)	Does not achieve.	9	9	9	10	10	10	10	11	13
			Clamming Areas	Does not achieve.	9	9	9	10	10	10	10	11	13
	RAO 3	29 COCs [d]		Not expected to achieve all PRGs.	39 [m]	9	9	10	10	10	10	11	13
	RAO 4	Total PCBs	English Sole	10	9	9	9	10	10	10	10	11	13
			Brown Rockfish	25	9	9	9	10	10	10	10	11	13
Short-term Effectiveness Ranking Guide				*The alternatives are ranked relative to each other, with five stars representing the most effective in the short term, and one star representing the least effective in the short term. The ranking considers the metrics above, summarized as the following three categories, which are considered in equal proportion: 1) community and worker protection during construction, which includes the duration of hazardous work (diver-assisted dredging); 2) environmental impacts from construction, including as a result of dredge releases, transportation, consumed landfill capacity, air emissions, energy consumption, and carbon footprint during implementation; and 3) the time to achieve RAOs (as a measure of the residual risk that is present on site until the RAOs are met).*									

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

Evaluation Criteria	Alternative									
	No Action	**1A(12)**	**1B(12)**	**1C+(12)**	**2B(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**2C+(7.5)**	**3E(7.5)**
Summary of Short-term Effectiveness	*No construction impacts.* *Not predicted to achieve RAOs.*	*Lowest construction impacts of the action alternatives.* *The longest time to achieve RAOs of the action alternatives.*	*1B(12) has low construction impacts.* *The shortest time to achieve RAOs compared to the other action alternatives.*	*1C+(12) is similar to 1B(12) but with additional construction impacts and risks associated with diver-assisted hydraulic dredging alternatives.* *Shortest time to achieve RAOs compared to the other action alternatives.*	*2B(12) has relatively low construction impacts (1 year longer than 1B(12)).* *Slightly longer time (1 year longer) to achieve RAOs compared to 1B(12) and 1C+(12).*	*2C+(12) is similar to 2B(12) but with additional construction impacts and risks associated with diver-assisted hydraulic dredging alternatives.* *Slightly longer time to achieve RAOs (1 year longer) compared to 1B(12) and 1C+(12).*	*3B(12) has moderate impacts.* *Slightly greater time to achieve RAOs compared to 1B(12) and scores slightly lower.*	*3C+(12) is similar to 3B(12) but with additional construction impacts and risks associated with diver-assisted hydraulic dredging alternatives.* *Slightly longer time to achieve RAOs (1 year longer) compared to 1B(12) and 1C+(12).*	*2C+(7.5) is similar to 2C+(12) but with additional construction impacts due to a longer construction duration.* *Longer time to achieve RAOs (2 years longer) compared to 1B(12) and 1C+(12).*	*3E(7.5) has the largest construction impacts from the most removal and risks associated with extensive diver-assisted hydraulic dredging.* *Longest time to achieve RAOs behind 1A(12) and the No Action Alternative.*
Ranking [a] for short-term effectiveness	★	★★	★★★★★	★★★★	★★★★	★★★	★★★★	★★★	★★	★
Implementability										
Technical Implementability	No construction (beyond source control implemented under different programs).	Shortest construction period. Lowest potential for difficulties and delays and impacts to EW tenants and users. No technical challenges associated with implementing MNR in underpier areas for Alternative 1A(12).	Shortest construction period. Low potential for difficulties and delays and impacts to EW tenants and users. Few technical challenges associated with implementing ENR for Alternative 1B(12).Technical challenges associated with the use of in situ treatment employed in underpier areas.	Shortest construction period. Low potential for difficulties and delays and impacts to EW tenants and users. Significant technical challenges and safety concerns associated with diver-assisted hydraulic dredging. Few technical challenges associated with implementing ENR for 1C+(12). Technical challenges associated with in situ treatment employed in underpier areas.	Moderate construction period and moderate potential for difficulties and delays and impacts to EW tenants and users. Technical challenges associated with in situ treatment in underpier areas.	Moderate construction period and moderate potential for difficulties and delays. Significant technical challenges and safety concerns associated with diver-assisted hydraulic dredging. Technical challenges associated with in situ treatment employed in underpier areas.	Moderate construction period and moderate potential for difficulties and delays. Technical challenges associated with the use of in situ treatment employed in underpier areas.	Moderate construction period and moderate potential for difficulties and delays. Significant technical challenges and safety concerns associated with diver-assisted hydraulic dredging. Technical challenges associated with in situ treatment employed in underpier areas.	Moderate construction period and moderate potential for difficulties and delays. Significant technical challenges and safety concerns associated with diver-assisted hydraulic dredging. Technical challenges associated with in situ treatment employed in underpier areas.	Longest construction period. Highest potential for difficulties and delays and impact to EW tenants and users. Significant technical challenges and safety concerns associated with multiple years of diver-assisted hydraulic dredging. Technical challenges associated with in situ treatment employed in underpier areas.

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

Evaluation Criteria	Alternative									
	No Action	**1A(12)**	**1B(12)**	**1C+(12)**	**2B(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**2C+(7.5)**	**3E(7.5)**
Administrative Implementability	No contingency actions (beyond source control implemented under different programs).	Lower overall scope. Largest potential for contingency actions in 31 acres of partial removal and ENR-nav, ENR-nav, ENR-sill, and MNR. Reauthorization of a small part of the federal navigation channel (Shallow Main Body – South) will be required.	Low overall scope. Similar potential for contingency actions as 1A(12) in 31 acres of partial removal and ENR-nav, ENR-nav, ENR-sill, and in situ treatment. Reauthorization of a small part of the federal navigation channel (Shallow Main Body – South) will be required.	Low overall scope. Similar potential for contingency actions as 1A(12) in 29 acres of partial removal and ENR-nav, ENR-nav, ENR-sill, and in situ treatment. Reauthorization of a small part of the federal navigation channel (Shallow Main Body – South) will be required.	Moderate overall scope. Potential contingency actions in 3 acres of ENR-sill, and 12 acres of in situ treatment. Reauthorization of a small part of the federal navigation channel (Shallow Main Body – South) will be required.	Moderate overall scope. Potential contingency actions in 3 acres of ENR-sill and 10 acres of in situ treatment. Reauthorization of a small part of the federal navigation channel (Shallow Main Body – South) will be required.	Moderate overall scope. Potential contingency actions in 1 acre of ENR-sill and 12 acres of in situ treatment.	Moderate overall scope. Potential contingency actions in 1 acre of ENR-sill and 10 acres of in situ treatment.	Moderate to high overall scope. Potential contingency actions in 3 acres of ENR-sill and 11 acres of in situ treatment.	Largest overall scope of cleanup. Least potential for contingency actions in 1 acre of ENR-sill.
Implementability Ranking Guide	*The alternatives are ranked relative to each other, with five stars representing the most implementable, and one star representing the least implementable. The ranking considers the following primary metrics considered equally: 1) technical implementability, with the key differentiating factor being the approach to remediating the technically challenging sediments under the piers; and 2) administrative implementability, with the key differentiating factor being the overall complexity of the cleanup, which accounts for annual challenges of permitting, fisheries coordination, Port tenant and shipping vessel coordination, and staging. Contingency actions are also included in the ranking for implementability; however, this is considered a secondary metric which is weighted less in the overall ranking because contingency actions are potential conditions only.*									
Summary of Implementability	*Most implementable of the alternatives.*	*Most implementable of the action alternatives.*	*Less implementable compared to 1A(12) due to challenges with in situ treatment in underpier sediment.*	*Less implementable compared to 1B(12) due to challenges with diver-assisted hydraulic dredging in addition to also implementing in situ treatment.*	*Similar implementability as 1B(12) due to similar technology challenges in open-water and underpier areas.*	*Similar implementability as 1C+(12) due to similar technology challenges in open-water and underpier areas.*	*Similar implementability as 1B(12) due to similar technology challenges in open-water and underpier areas.*	*Similar implementability as 1C+(12) due to similar technology challenges in open-water and underpier areas.*	*Similar implementability as 1C+(12) due to similar technology challenges in open-water and underpier areas.*	*Least implementable of the alternatives due to extensive diver-assisted hydraulic dredging and large scope of open-water remediation.*
Ranking [a] for implementability	★★★★★	★★★★	★★★	★★	★★★	★★	★★★	★★	★★	★
Costs										
Costs Ranking Guide	*The No Action Alternative is ranked five stars as the least expensive. The action alternatives are ranked relative to each other, with four stars representing the least expensive, and one star representing the most expensive. The action alternatives are grouped based on ranges of costs, using intervals of $30 million each (i.e., $240 to $270 million, $270 to $300 million, $300 to $330 million, and more than $330 million).*									
Total Costs ($)	950,000	256,000,000	264,000,000	277,000,000	284,000,000	297,000,000	298,000,000	310,000,000	326,000,000	411,000,000
Ranking [a] for costs	★★★★★	★★★★	★★★★	★★★	★★★	★★★	★★★	★★	★★	★

Notes:

a. The alternatives are ranked from one star to five stars relative to the other alternatives, and also considering the metrics used to evaluate the criterion, with more stars indicating a more favorable ranking. See Sections 10.2.1.3, 10.2.2, 10.2.3.4, 10.2.4.1, and 10.2.5 for guidance on interpretation of rankings.

b. Risk estimates are based on the use of the total PCB and dioxin/furan SWACs in the FWM and BSAF, respectively. Risks due to cPAHs, which are based on clam consumption, are not included because cPAHs in clam tissue were not calculated due to the poor relationship between sediment and tissue values in the SRI dataset.

c. See Tables 9-5a and 9-5b for other RME risk scenarios.

d. For FS purposes, achievement of RAO 3 is based on at least 98% of predicted surface sediment locations achieving PRGs for all 29 benthic COCs. Compliance with SMS benthic criteria will be determined based on SMS requirements. Predictive modeling was not conducted for the No Action Alternative for compliance of RAO 3; therefore, the percentage of surface sediment locations below PRGs are presented for existing conditions (see Table 9-3).e. In the context of long-term effectiveness and permanence, different technologies have different magnitude of residual risk because they leave different amounts of contamination on site and use different engineering controls.

f. The total number of core stations is 146; 1 in the underpier areas and 145 in open-water areas. All 76 cores with one or more CSL exceedances are in open-water areas. The number of core stations post-construction remaining exceeding the SQS (but below CSL) are presented in Table 9-10.

g. Construction timeframe rounded up to the nearest year, assuming some concurrent removal and material placement (see Table 8-6 for details). As described in Section 8.1.1.8, the Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15. However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15 (i.e., 100 days/season). It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15); thus, the upper end of the number of work days in a construction season could increase to around 150 days/season, reducing the total number of years of construction by about 2 years for all action alternatives. However, the total number of construction days and associated construction impacts would remain unchanged.

h. The landfill capacity consumed is proportional to the volume of dredged material removed and disposed of in the landfill (assuming a 20% bulking factor).

i. One acre-year represents the amount of CO_2 sequestered by 1 acre of Douglas fir forest for 1 year. Carbon footprint in units of acre-years is appropriate to compare the alternatives differences in CO_2 releases over the entire project.

j. Some RAO metrics are achieved immediately after construction. If a longer construction window is allowed (see footnote above), the number of years of construction and corresponding time to achieve the RAOs would decrease by about 2 years for all action alternatives (see Section 9.1.2.3).

k. The orders of magnitude risk values presented for time to achieve RAOs were selected to most differentiate the alternatives. Alternative compliance is based on attaining the PRGs or target risk thresholds. Times to achieve RAOs could be reduced if a longer construction window is allowed, as the total number of years of construction could decrease by 2 years for all action alternatives (see Section 9.1.2.3).

l. Achievement of RAO 2 is based on meeting PRG (arsenic). All action alternatives are predicted to meet the arsenic RAO 2 PRG of 7 mg/kg dw following construction, but increase above the PRG in the long term due to the Green River input concentrations (Section 9.15.1.2). All alternatives, including the No Action Alternative, may meet the PRG in the long term, depending on actual site conditions.

m. Time to achieve RAO 3 PRG based on total PCBs; all other benthic risk driver COCs achieve PRGs immediately after construction completion.

Abbreviations:

API – Asian Pacific Islander
ARAR – applicable or relevant and appropriate requirements
BSAF – Biota-Sediment Accumulation Factors
CO_2 – carbon dioxide
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
cy – cubic yards
CSL – cleanup screening level
dw – dry weight
ENR-nav – enhanced natural recovery used in the navigation channel or berthing areas
ENR-sill – enhanced natural recovery used in the sill reach
EPA – U.S. Environmental Protection Agency
EW – East Waterway
FS – Feasibility Study
FWM – Food Web Model
HQ – hazard quotient
LOAEL – lowest observed adverse effect level
mg/kg – milligrams per kilogram
MLLW – mean lower low water
MNR – monitored natural recovery
MJ – megajoule
MTCA – Model Toxics Control Act
NA – not applicable
OC – organic carbon
PCB – polychlorinated biphenyl
PM_{10} – particulate matter less than 10 microns in diameter
PRG – preliminary remediation goal
RAL – remedial action level
RAO – remedial action objective
RME – reasonable maximum exposure
RNA – restricted navigation areas
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SRI – Supplemental Remedial Investigation
SWAC – spatially-weighted average concentration
TRV – toxicity reference value

10.1 Threshold Criteria

The two threshold criteria are:

1. Overall protection of human health and the environment
2. Compliance with ARARs

10.1.1 Overall Protection of Human Health and Environment

This criterion addresses whether an alternative provides adequate protection of human health and the environment. EPA guidance (1988) states that the assessment of overall protection draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and short-term effectiveness, as discussed in the following sections.

10.1.1.1 Overall Protection – Long-term Effectiveness and Permanence

For this evaluation, long-term effectiveness and permanence have two major aspects, as follows:

1. The magnitude and type of residual risks to humans, wildlife, and the benthic community
2. Engineering and institutional controls used to mitigate those residual risks

Magnitude and Type of Residual Risks

As discussed in Section 4, RAOs were developed for protection of people who use the waterway, the benthic community, fish, and wildlife. Table 10-1 summarizes the predicted residual risks achieved for each alternative for each RAO.

The No Action Alternative is predicted to achieve RAO 4 but not RAOs 1, 2, or 3. The action alternatives are predicted to achieve all the RAOs.

While the action alternatives are not predicted to achieve the natural background-based PRGs for RAO 1 for total PCBs or dioxins/furans, they are predicted to achieve similar reductions in risks. For example, all action alternatives, with the exception of Alternative 1A(12), are predicted to achieve a residual total excess cancer risk of 2×10^{-4} for the Adult Tribal seafood consumption RME scenario, 4×10^{-5} for the Child Tribal seafood consumption RME scenario, and 9×10^{-5} for the Adult API RME scenario 40 years after construction completion. Alternative 1A(12) is predicted to achieve 3×10^{-4}, 5×10^{-5}, and 1×10^{-4} for the three scenarios, respectively. In addition, the residual non-cancer HQs for total PCBs[149] are predicted to be similar for all action alternatives, 4 to 5 for the Adult Tribal RME scenario, 9 to 12 for the Child Tribal RME scenario, and 4 to 5 for the Adult API RME scenario (see Tables 9-5a through 9-5d).

For RAO 2, all alternatives are predicted to achieve a total excess cancer risk of less than 1×10^{-5}. For arsenic, the action alternatives are predicted to meet the natural-background-based PRG following construction, but increase above the PRG in the long term due to incoming Green River concentrations. The No Action Alternative is not predicted to meet the arsenic PRG (see Tables 9-2 and 9-6).

For RAO 3, the No Action Alternative is not expected to achieve the benthic PRGs. Alternative 1A(12) is predicted to meet benthic PRGs in 99% of point locations 40 years following construction. Alternatives 1B(12) through 3E(7.5) are predicted to meet benthic PRGs in 100% of point locations after construction completion (see Table 9-3).

For RAO 4, the No Action Alternative does not achieve an HQ less than 1.0 using the lower LOAEL TRV, but does achieve an HQ less than 1.0 using the higher LOAEL TRV (see Table 9-7). The No Action Alternative is predicted to meet both PRGs within 25 years (see Table 9-1a). All action alternatives are predicted to achieve an HQ less than 1.0 for English sole (using either LOAEL TRV) and for brown rockfish (using the higher LOAEL TRV). An HQ ranging from 1.0 to 1.3 for brown rockfish is achieved using the lower LOAEL TRV (the HQ is greater than 1.0 because of influence of receiving water PCB concentrations; see Table 9-7). All action alternatives are predicted to meet the PRGs following construction (see Table 9-1a).

Adequacy and Reliability of Controls

Adequacy and reliability of controls includes the engineering and institutional controls used to limit and manage risks associated with contaminated sediments that remain for each alternative.

[149] Based on the immunological, integumentary, or neurological endpoints.

The No Action Alternative provides no engineering controls. The action alternatives rely primarily on dredging (64% to 94% of the remedial footprint depending on the alternative), followed by partial dredging and capping (5% to 11% of the remedial footprint depending on the alternative), and therefore employ important engineering controls. Table 10-1 provides the areas of capping, partial removal and ENR-nav/ENR-nav, ENR-sill, in situ treatment, diver-assisted hydraulic dredging, and MNR for the alternatives to approximate the area with subsurface contamination remaining following construction and to indicate the additional engineering controls (e.g., monitoring and maintenance) required for each area.

The reliability of engineering controls varies according to the remedial technology used. Mechanical dredging in open water areas is generally considered the most reliable technology over the long term because less contaminated sediment remains on site following remediation. Diver-assisted hydraulic dredging in underpier areas is considered less reliable because riprap, debris, and structural supports prevent sediment from being completely removed. Capping is considered very reliable over the long term because contaminated sediment is isolated below an engineered and monitored layer of material. ENR and in situ treatment, although designed for the conditions where they will be used, are considered less reliable because they depend on more complicated chemical and physical processes, such as sedimentation and contaminant adsorption. MNR has the lowest reliability because it relies entirely on the reduction of contaminated sediment concentrations through a combination of natural processes (e.g., physical, biological, and chemical). All remedial technologies include monitoring and potential contingency actions to increase their reliability over time.

The No Action Alternative provides no institutional controls beyond those that are currently in place (e.g., existing consumption advisories). All of the action alternatives would all have similar types of institutional controls, which would be adequate when coupled with outreach, education, and engineering controls (i.e., active remediation) that form the basis of these alternatives. Institutional controls are used to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants. As discussed in Section 7.2.2, an ICIAP for the EW would include a notification, monitoring, and reporting program for areas of the EW where contamination remains in place to ensure the performance of the remedy. This program may include elements such as proprietary controls and designation of RNAs in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. In addition, the ICIAP will include seafood consumption advisories and public outreach and education programs as necessary.

10.1.1.2 Overall Protection – Short-term Effectiveness

Overall protectiveness of the alternatives can also be discerned in the context of short-term effectiveness, which includes impacts during the construction phase (the time required to implement the remedy) and the time to achieve RAOs.

Alternatives with shorter construction periods and less total sediment removal translate into lower impacts to workers, the community, and the environment during implementation. Predicted impacts during construction include traffic, noise, worker injuries/fatalities, dredge material resuspension and releases, air pollutant emissions, natural resource depletion, physical disruption of aquatic habitat, and elevated fish and shellfish tissue contaminant concentrations (see Section 10.2.3). In general, the impacts from construction are greatest for dredging, relatively high for capping, and significantly reduced for ENR, in situ treatment, and MNR. Impacts are generally considered proportional to total construction time; however, short-term impacts to workers are expected to be larger for alternatives with diver-assisted hydraulic dredging due to the hazards associated with underpier, deep water work.

The No Action Alternative has no active remediation, and therefore, has no short-term impacts from construction activities beyond monitoring. All of the action alternatives have significant construction-related impacts that are necessary to remediate the EW (i.e., meet the RAOs) and maintain site uses. The action alternatives range from 9 years of construction and 810,000 cy of sediment removed from the waterway for Alternative 1A(12), to 13 years of construction and 1,080,000 cy of sediment removed for Alternative 3E(7.5).

While the No Action Alternative is not predicted to achieve all RAOs, all of the action alternatives are predicted to achieve RAOs. The action alternatives are predicted to achieve PRGs for RAOs 2 through 4 immediately following construction, with the exception of Alternative 1A(12), which is predicted to achieve RAO 3 in 39 years from the start of construction. In addition, all of the action alternatives achieve similar risk reductions toward meeting RAO 1, and the time to achieve RAO 1 is expected to be similar for any of the action alternatives.

10.1.1.3 Overall Protection Summary

The No Action Alternative does not provide adequate protection of human health and the environment, engineering controls, or institutional controls and does not achieve all of the RAOs; therefore, it does not achieve threshold criteria. All of the nine action alternatives are sufficiently effective in the short term and the long term to meet threshold requirements.

In the long term, the action alternatives achieve significant risk reduction using reliable remedial technologies, achieve the CERCLA risk range of 10^{-4} to 10^{-6}, and include monitoring and institutional controls to measure and ensure risk reduction.

In the short term, alternatives with larger removal volumes and longer construction times present proportionately greater risks to workers, the community, and the environment. Longer construction periods increase equipment and vehicle emissions, noise, and other resource use. Construction durations range from 9 to 13 years, due to the large scope of dredging for all alternatives. Most impacts due to construction vary proportionally with construction duration; however, short-term impacts to workers are expected to be larger for alternatives with diver-assisted hydraulic dredging due to the hazards associated with underpier, deep water work. The action alternatives are predicted to achieve PRGs for RAOs 2 through 4. None of the action alternatives achieve the natural background-based PRGs for RAO 1, but achieve similar risk reduction toward meeting RAO 1.

10.1.2 Compliance with ARARs

The two most important ARARs in terms of evaluating the alternatives are MTCA (statute and regulations) and state surface water quality standards and federal recommended water quality criteria.

MTCA Compliance

Part V of the SMS (WAC 173-204) is promulgated under MTCA and establishes requirements for remediation of contaminated sediment. The nine action alternatives have been developed to be compliant with SMS. In particular, SMS (WAC 173-204-560) provides rules for developing cleanup levels considering multiple exposure pathways, background concentrations, and PQLs. The PRGs were developed to be consistent with the rules for cleanup level determination in SMS, but without considering regional background as it has not been defined for this area (see Appendix A for additional details).

All of the action alternatives are expected to comply with MTCA/SMS standards for protectiveness of human health for direct contact (RAO 2), protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) through active remediation, and additional MNR for Alternative 1A(12) only. For protection of human health for seafood consumption (RAO 1), none of the action alternatives are predicted to achieve the natural background PRGs for PCBs or dioxins/furans, due to model input parameters that assume ongoing contribution of contaminants from diffuse nonpoint sources upstream of the EW. Although the SMS allows for use of a regional background-based cleanup level if it is not technically possible to meet and maintain natural background levels, regional background levels have not yet been established for the geographic area of the EW.

However, CERCLA compliance with MTCA/SMS ARARs may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are much lower than current model predictions, and PRGs identified in this FS are attained in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

Water Quality Standards Compliance

All of the alternatives must comply substantively with relevant and appropriate state water quality standards and any more stringent recommended federal surface water quality criteria upon completion of the remedial action, except to the extent that they may be formally waived by EPA. Dredging and construction projects previously implemented in the EW OU have complied with project-specific water quality certification requirements. Compliance with these or similar certification requirements can be expected regardless of the alternative selected, provided that dredging methods include BMPs to ensure that dissolved and suspended releases (e.g., of COCs and TSS) do not result in exceedances of water quality standards (EPA 2005; NRC 2007; USACE 2008b). Implementing multiple remedial actions simultaneously and in relatively close proximity to one another could increase the risk of violating short-term water quality requirements, a consideration that should be factored into project sequencing and production rate decisions. Careful planning, production rate controls, and the use of BMPs are warranted in all cases to reduce short-term water quality impacts.

Cleanup of sediments, along with source control actions, are expected to reduce concentrations of COCs, such as total PCBs, in the water column following cleanup actions. Other factors not related to releases from the site (e.g., inflow of river water from upstream, marine water from downstream, or aerial deposition of COCs from distant sources) also contribute to COC concentrations in water. Currently, Green River upstream and Elliott Bay downstream water concentrations appear to be above federal recommended human health water quality criteria for total PCBs and arsenic. If long-term monitoring data and trends indicate that water quality ARARs cannot be met, EPA will determine whether further remedial action could practicably achieve the ARAR. If EPA concludes that an ARAR cannot be practicably achieved, EPA may waive the ARAR on the basis of TI in a future decision document (ROD Amendment or ESD).

Compliance with Other ARARs

The construction elements for the alternatives are similar in nature and scope to sediment remediation projects previously implemented in the Puget Sound region. It is therefore anticipated that all of the alternatives can be designed and implemented to comply with ARARs including the following:

- **Management and disposal of generated materials (e.g., contaminated sediment, wastewater, and solid waste).** These ARARs primarily concern the handling and disposal of materials. They may complicate implementation and add costs but should not influence whether an alternative is fundamentally viable.
- **Resource protection requirements (e.g., habitat preservation and mitigation).** These do not pose a fundamental obstacle to the design and implementation of the alternatives. In the short term, the benthic community within the intertidal and shallow subtidal habitat areas above -10 feet MLLW, which are critical habitats to outmigrating salmonids and important intertidal habitats, would be impacted during dredging and capping activities. In these areas, benthic organisms must recolonize in the biologically active zone and regain ecological functions following remediation.

CWA 404 dredge and fill requirements can be met for all alternatives. As with previous regional CERCLA sediment remediation projects, EPA would evaluate the selected alternative for substantive compliance with CWA 404(b)(1) and Rivers and Harbors Act Section 10 requirements. Specific design elements would ensure that these requirements are satisfied.

10.2 Balancing Criteria

The alternatives were compared using the five balancing criteria designated by CERCLA. The subsections below present the comparison.

10.2.1 Long-term Effectiveness and Permanence

This balancing criterion compares the relative magnitude and type of residual risk that would remain in the EW after remediation under each alternative. In addition, it assesses the extent and effectiveness of the controls that may be required to manage the residual risks from contamination remaining at the site after remediation (Section 9.1.2.1).

10.2.1.1 Magnitude and Type of Residual Risk

The alternatives were evaluated for two types of residual risks following cleanup. The first type is the risk predicted to remain on site from exposure to surface sediment contaminant concentrations after the completion of remediation and over time. The second type of residual risk is from contaminated sediments remaining in the subsurface after remediation (e.g., under caps or in areas remediated by ENR, in situ treatment, or MNR), which may be exposed in the future through disturbance.

Residual risks to humans, the benthic community, and fish from surface sediment COC concentrations after remediation were estimated and described in Section 9 and in Table 10-1. All of the alternatives, except the No Action Alternative, are predicted to achieve similar residual surface sediment COC concentrations and risk levels in the long term.

Evaluation of residual risks also considered the potential for exposure of subsurface contamination left in place following remediation. Mechanisms for deep disturbance of subsurface sediment including vessels maneuvering under typical and extreme operations, ship groundings, and operations such as pier maintenance activities, may occur on a recurring basis in a working industrial waterway like the EW. Most open-water areas, excluding areas with caps, will be potentially subject to propwash disturbances ranging from 0.5 to 5 feet. The majority of the EW could experience scour depths of 2 feet or greater under normal to extreme operating conditions, and such mixing, dependent on vessel operation areas, has been incorporated into the long-term performance modeling (Section 9.2.1). Another type of disturbance includes earthquakes, which could potentially expose subsurface contaminated sediment, but their impacts in the waterway would be minimal compared to potential for disturbance from upland liquefiable soils, slope failures, and spills that would impact the bed of the EW (Section 2.14.5).

All of the action alternatives emphasize removal of contaminated sediments, and thus, have a low potential for subsurface sediment to be exposed. Table 10-1 contains the following metrics, developed and presented in Section 9, that were used to compare the magnitude of subsurface contamination remaining in place and the potential for it to be exposed for each alternative:

- **Long-term Risk Outcomes:** Section 10.1.1.1 describes the long-term risk outcomes for the alternatives. All of the action alternatives achieve similar risk outcomes, with Alternative 1A(12) having slightly higher risks due to the use of MNR under the piers. In addition, the effectiveness of MNR is more uncertain than active remedial technologies. The other underpier technology options (i.e., the B, C+, and E alternatives) result in the same long-term risk outcomes and therefore, in situ treatment is as effective as underpier removal. In addition, there is no difference in long-term risk among the open-water technology options (i.e., the 1, 2, and 3 alternatives), or among the different RAL options (i.e., the (12) and (7.5) alternatives).
- **Area dredged in open-water and under piers:** Subsurface contaminated sediment is removed in these areas, as follows:
  - Alternatives 1A(12), 1B(12), and 1C+(12) perform removal over 77 to 79 acres of the EW
  - Alternatives 2B(12) and 2C+(12) perform removal over 94 to 96 acres of the EW
  - Alternatives 3B(12), 3C+(12), and 2C+(7.5) perform removal over 100 to 106 acres of the EW
  - Alternative 3E(7.5) performs removal over 124 acres of the EW
- **Area partially dredged and capped:** The risk of exposing contaminated subsurface sediment is relatively low in capped areas because the caps are engineered to remain structurally stable under location-specific conditions and provide a high degree of protectiveness. All action alternatives perform a similar degree of partial dredging and capping, ranging from 7 acres (Alternatives 3B(12), 3C+(12), and 3E(7.5)), to 13 acres (Alternatives 1A(12), 1B(12), 1C+(12), 2B(12), 2C+(12), and 2C+(7.5)).
- **In situ treatment, partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR:** Areas remediated by in situ treatment, partial removal and ENR-nav/ENR-nav, ENR-sill, or MNR have a higher potential for exposure of contaminated subsurface sediment as a result of disturbance, such as from propwash, than capped areas because, unlike caps, these technologies are not engineered to completely isolate subsurface contaminated sediments. In situ treatment is considered more permanent than partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR because in situ treatment permanently binds and reduces the bioavailability of hydrophobic organic compounds (e.g., PCBs) by an estimated 70% (see Section 7.2.7.1). Proposed in situ treatment, partial removal and

ENR-nav/ENR-nav, ENR-sill, and MNR areas represent a relatively small contribution (less than 20%) to the overall EW remedial footprint for alternatives: 29 to 31 acres for Alternatives 1A(12), 1B(12), and 1C+(12); 11 to 15 acres for Alternatives 2B(12), 2C+(12), 2C+(7.5), 3B(12), and 3C+(12); and 1 acre for Alternative 3E(7.5). However, the effect of exposure of subsurface contamination due to disturbance is anticipated to be minimal for these technologies for the following reasons:

- The majority of the remedial footprint area is addressed through removal technologies.
- Predictive modeling of impacts from disturbances indicates minimal effect to overall concentrations. Sediment mixing due to vessel scour has been incorporated into predictions of surface sediment concentrations in the FS (e.g., Table 9-1a). In scour areas (e.g., the navigation channel), the upper 2 feet of sediment is assumed to be mixed every 5 years in 50% of the area (Section 5). In underpier areas, sediment is assumed to be mixed with a portion exchanged with open-water areas every 5 years. Therefore, the predicted surface sediment concentrations account for the effect of vessel scour by assuming that subsurface sediment, surface sediment, and placed material (e.g., ENR material) are periodically mixed.
- Specification of aggregate mixes for ENR material can be designed and implemented to reduce impacts from the types of scour associated with vessel operations.
- Monitoring and adaptive management of these areas would trigger contingency actions if subsurface contamination is exposed.

- **Number of core stations outside of the dredge footprint:** The number of core stations with samples exceeding the CSL remaining following construction was used as a quantitative measure of contamination left behind. The action alternatives remove between 66 and 71 core stations (of a total of 76) that exceed the CSL. In addition, the majority of cores with CSL exceedances remaining after remediation are located under isolation caps for all alternatives. The alternatives leave up to 3 cores with CSL exceedances in ENR-sill and no action areas, with Alternatives 1A(12), 1B(12), 1C+(12), 2B(12), and 2C+(12) leaving 3 cores behind, Alternatives 3B(12) and 3C+(12) leaving 2 behind, Alternative 2C+(7.5) leaving one core behind, and

Alternative 3E(7.5) leaving no cores behind. No cores exceed the CSL in MNR and in situ treatment areas for any of the alternatives.

- **The volume of contaminated sediment remaining after remediation** that could be disturbed by potential propwash erosion is reflected in the metrics above. In particular, the box model incorporates subsurface contaminant mixing (2 feet over much of the waterway), and therefore the predicted long-term risks include the contribution of any remaining contamination being transported by propwash into surface sediments. For the No Action Alternative, an estimated volume of 390,000 cy of contaminated sediment could be disturbed by propwash erosion.[150]

10.2.1.2 Adequacy and Reliability of Controls

This factor assesses the adequacy and reliability of controls used to manage residual risks from contaminated sediment that remains on site following remediation. As discussed in Section 10.2.1.1, the relative magnitude and importance of the post-remediation control components for the alternatives differ, primarily in relation to the potential for exposure of subsurface contaminated sediment under caps, and in MNR, partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas and the size of the disturbance event. The alternatives vary in amounts of monitoring, maintenance, and institutional controls used to manage residual risks and the potential for recontamination.

For this evaluation, adequacy and reliability of controls have five major aspects, as follows:

1. Controls of dredge residuals
2. Source control
3. Monitoring
4. Maintenance
5. Institutional controls

[150] Volume calculated by multiplying the area of sediment that exceeds RALs for the majority of the action alternatives (121 acres, which considers the upper 2 feet of sediment in potential propwash areas) by a potential mixing depth of 2 feet.

Control of Dredge Residuals

All dredging projects leave behind some level of residual contamination immediately after completion of in-water work (USACE 2008b). Dredge residuals are produced by the resettling of sediments suspended during dredging, subsequent disturbance, and transport of the material just outside the dredged area (coarser resuspended material) or well beyond the dredge operating area (fine-grained material) (USACE 2008b; Bridges et al. 2010; Patmont and Palermo 2007). Surface sediments in the EW will be affected to some degree by dredge residuals following remediation. The management of dredge residuals was acknowledged in the development of alternatives (Section 8) with a cost and modeling assumption that dredging would be followed by a thin-layer placement of RMC sand layer as an engineering control for dredge residuals. The dredge residuals management approach and decision framework will be developed during remedial design (Appendix B, Part 5).

Source Control

Potential sources to the EW are regulated under existing state and federal programs. EW source control evaluations and actions to date include source tracing and line cleaning.[151] In addition, programs such as spill response and business inspections are conducted in the EW drainage basins as part of compliance with NPDES permit requirements (e.g., for stormwater and CSO discharges) and MTCA (e.g., for upland cleanup sites adjacent to the EW). These programs enforce stringent federal and state standards (e.g., the CWA), and incorporate reporting and review cycles for transparency, corrective action, and adaptive management. A summary of each source control-related program and how it relates to the EW source control strategy is provided in Section 2.12.2. Under any of the FS alternatives, incoming solids from local lateral inputs are addressed under ongoing source control programs.

The box-model sensitivity evaluation in Appendix J indicates that lateral sources have a minor impact on site-wide SWACs compared to upstream sources, and therefore, are not a major driver for reducing site-wide risks. In addition, the recontamination evaluation presented in Section 9.14 predicts that the potential for recontamination above RALs in very localized areas near some outfalls and may occur in the EW for a few contaminants

[151] Source tracing and line cleaning in City storm drains has been performed voluntarily.

(dioxins/furans, BEHP, mercury, and 1,4-dichlorobenzene). A source control sufficiency evaluation will be completed prior to remedy construction.

As discussed in Appendix K, direct atmospheric deposition to the EW surface does not appear to be a major pathway for most contaminants to the EW, although it could be comparable to EW lateral inputs for some COCs, specifically for BEHP and dioxins/furans. Estimates of inputs from atmospheric deposition have not been incorporated into modeling for recontamination potential or future SWACs; therefore, there is some uncertainty associated with its overall impact. In addition, indirect atmospheric deposition to drainage basins could be a significant contribution the EW lateral loads.

Persistent legacy compounds such as total PCBs can be expected to diminish over time as a result of ongoing source control. Other contaminants (e.g., cPAHs, dioxins/furans, and phthalates) continue to be generated and released into the environment from a variety of non-point sources (e.g., vehicles, combustion of organics, and PVC). Technological advances or societal changes (e.g., energy use, transportation, infrastructure investment [particularly in source control], and waste generation, handling, and recycling) and many other possible factors will continue to affect ongoing inputs to the EW. Collectively, the pace and efficacy of these factors make predictions for the EW uncertain. However, ongoing sources will affect the adequacy and reliability of all alternatives equally, so, while important, source control does not factor into the comparative analysis of alternatives.

Monitoring

Monitoring is a key assessment technology for sediment remediation. Monitoring of surface and subsurface sediment, fish and shellfish tissue, porewater, and surface water quality will be required for any alternative selected for cleanup of the EW. Pre-construction baseline monitoring will be conducted to establish baseline conditions for comparison to post-construction performance monitoring results. During construction, location-specific construction monitoring data and confirmation sampling will be used to verify the performance of the operations and identify the need for construction contingencies, such as the placement of RMC following dredging. Operations and maintenance monitoring methods will be used to measure the post-construction and long-term performance of the remedial technologies (such as MNR). Finally, long-term EW-wide monitoring data will also

be used to assess the post-construction and long-term performance of remediation with respect to achievement of RAOs (that ensure protection of human health and the environment) and to identify sediment recontamination.
Differences among the alternatives in the adequacy and reliability of long-term post-cleanup monitoring are minor. The scope and duration of monitoring are similar for the action alternatives. However, alternatives with MNR, ENR, and in situ treatment components would require the collection of more project-specific operation and maintenance monitoring data to achieve data quality objectives, and have more potential for contingency actions in the future.

As previously stated, the entire EW will require monitoring under all alternatives, including the underpier area using any technology assignment. The difference among the alternatives is whether they have large, moderate, or small surface areas that require technology-specific performance monitoring (i.e., cap, ENR, in situ treatment, and MNR) during the monitoring period (Table 10-1). For the No Action Alternative, only site-wide monitoring was assumed. For the action alternatives, the monitoring scope is similar due to the similar scope of the alternatives (i.e., primary reliance on removal, with some reliance on partial removal and capping, ENR, in situ treatment, and MNR depending on the alternative) with differences due to the differences in acres of MNR, ENR, and in situ. Appendix G presents the assumed scope of monitoring for the alternatives.

Maintenance

After construction, long-term monitoring is useful in identifying and assessing remediated areas that may not perform as anticipated (e.g., cap instability). Therefore, maintenance may be required to address needed repairs and adaptive management responses (including contingency actions where appropriate), which would decrease the residual risk of post-remediation exposure to subsurface contaminated sediment.

Maintenance technologies are drawn from the same set of technologies used to develop the alternatives. The primary maintenance technologies are dredging or application of cover material (e.g., to repair a cap or ENR area).[152] These activities are performed using the same marine construction technologies employed during remedy construction. These technologies are as reliable for maintenance as they are for constructing the alternatives themselves, assuming that the engineering, planning, and execution of the repairs are done with a similar level of proficiency. As presented in Section 7.2.5.4, capping has been shown to be a successful, reliable, and proven technology, effective at many CERCLA sites within the Puget Sound where caps have been in place for more than 15 years and are performing as designed.

Alternatives with more removal have a reduced level of effort for maintenance compared to alternatives with more containment, ENR, and MNR. ENR, in situ treatment, and MNR areas are assumed to have a higher maintenance requirement (i.e., per unit area) compared to capping. The contribution of the maintenance evaluation factor to the ranking of the long-term effectiveness and permanence balancing criteria is qualitatively assessed by whether the alternatives have large, moderate, or small surface areas to maintain and whether a moderate or higher level of effort for monitoring or maintenance is expected (Table 10-1). Therefore, the comparison of alternatives with regard to maintenance requirements is the same as previously discussed for monitoring.

Institutional Controls

Institutional controls are needed for all alternatives because thresholds of excess cancer risk of 1×10^{-6} and non-cancer HQs less than 1 are associated with levels in sediment below natural background for total PCBs, dioxins/furans, and arsenic. In addition, none of the alternatives achieve natural background-based PRGs for total PCBs or dioxins/furans for RAO 1. Thus, remaining risks to the community from consuming resident fish and shellfish would be managed by institutional controls designed to reduce such seafood consumption exposures. While the No Action Alternative includes no provisions for site-wide institutional controls to manage residual risks, the action alternatives would require an ICIAP for the EW. The ICIAP would include several elements, such as a notification, monitoring, and reporting

[152] In developing the alternatives, a specific assumption was made that 15% of designated MNR, ENR, and in situ treatment areas of any given alternative will require additional remediation as a contingency action based on remedial design sampling or subsequent monitoring data.

program for areas of the EW and WDOH seafood consumption advisories, public outreach, and education programs.

Monitoring and notification of waterway users is essential where contamination remains in place above levels to ensure the performance of the remedy (particularly the containment-focused alternatives, in areas where capping has been utilized). The essential components of these programs, as discussed in Section 7.2.2.2, could include elements such as the following proprietary controls:

- Reviewing USACE dredging plans and other Joint Aquatic Resource Permit Application construction permitting activities to identify any projects with the potential to compromise containment remedies or potentially disturb contamination remaining after remediation. EPA would be notified during the permitting phase of any project that could affect containment remedies.[153]
- Using signs, RNAs, and other forms of public notice to inform waterway users about restrictions in areas where contamination remains in place.

The second element of the ICIAP includes seafood consumption advisories and public education and outreach programs. Dependence on these programs to reduce exposures may be more critical in the short term during construction periods because fish and shellfish tissue concentrations are predicted to remain elevated throughout the construction period and for some time thereafter, resulting in a period of continued elevated resident seafood consumption risks. As discussed in Section 7.2.2.2, WDOH issues seafood consumption advisories, although it is not necessarily the exclusive issuing authority.[154] Advisories are informational devices that are not enforceable against potential consumers of EW fish and shellfish, and they can have poor compliance. Thus, enhanced public education and outreach efforts are crucial to reduce exposures through changes in behavior (e.g., encouraging consumption of migratory fish, such as salmon, which are safer to eat than resident seafood in the EW). The education programs could be developed and administered by responsible

[153] This function is currently in place in the form of a Standard Operating Procedure agreed upon between EPA and USACE, and the existing mechanism could either be funded or assumed by the responsible parties.
[154] EPA may also select, design, and require implementation of seafood consumption advisories like any other institutional control to help reduce exposures to hazardous substances.

parties with EPA oversight and participation from local governments, tribes, and other community stakeholders.

10.2.1.3 Summary of Long-term Effectiveness and Permanence

For long-term effectiveness and permanence, the alternatives are ranked relative to other alternatives, with five stars representing the most effective in the long term and most permanent, and one star representing the least effective in the long term and least permanent. The ranking considers both factors described above, equally: 1) risk reduction achieved by the alternative in the long term and magnitude and type of residual risk remaining; and 2) adequacy and reliability of engineering controls, considering the area of the waterway with contamination permanently removed, and the area with remaining contamination that will require technology-specific monitoring and maintenance, beyond site-wide monitoring.

As shown in Table 10-1, the No Action Alternative has the lowest relative rank (★) for long-term effectiveness and permanence because it would not achieve all of the RAOs, it would leave the largest amount of subsurface contamination in place, and it would not provide reliable controls. All of the action alternatives are considered highly permanent due to a primary reliance on removal (between 80% and 99% of the remediation area undergoes removal or partial removal). Alternative 1A(12) ranks moderately (★★★) because it removes the least amount of contaminated sediment among the action alternatives, has slightly higher residual risks in the long term (due to reliance on MNR), and would leave an area managed without engineering controls (i.e., MNR). Alternatives 1B(12) and 1C+(12) rank higher (★★★★) because they achieve slightly lower risks than Alternative 1A(12), but would remove a similar amount of contaminated sediment as Alternative 1A(12) and have a larger area managed by ENR and in situ treatment. Alternatives 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), and 3E(7.5) score highest (★★★★★) because they achieve similar risks as among the action alternatives, and they rely more on removal than Alternatives 1B(12) and 1C+(12), and are therefore likely to be more permanent. All alternatives include little ENR and limited engineered (armored) capping, which is considered highly permanent for this evaluation.

10.2.2 Reduction in Toxicity, Mobility, or Volume through Treatment

This criterion assesses the degree to which site media are treated to permanently and significantly reduce the toxicity, mobility, or volume of site contaminants. Based on EPA guidance, the contaminated sediments within the EW are classified as low-level threat wastes because they are not highly toxic or highly mobile such that they generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur (Section 9.1.2.2).

All action alternatives, except for Alternative 1A(12), include in situ treatment using activated carbon or other sequestering agents as a remedial technology. Activated carbon lowers the mobility of contaminants, reducing the toxicity and bioavailability to biological receptors directly in areas where it is applied and indirectly site-wide through reduced releases to the water column, which lowers average exposure to receptors. The amendment material is often placed as part of a clay, sand, or gravel matrix to deliver the amendment to the sediments in a reasonably stable lift.

For FS comparison purposes, the reduction of mobility achieved by in situ treatment is assumed to be proportional to the area that undergoes treatment. The alternatives are ranked relative to each other, with those alternatives using the most use of in situ treatment relative to the other alternatives (e.g., > 10 acres) receiving five stars, and alternatives with no in situ treatment receiving one star. Alternatives 1B(12), 1C+(12), 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), and 3E(7.5) employ in situ treatment in underpier areas above RALs (varying from 12 to 13 acres) and therefore rank the highest (★★★★★) for this balancing criterion. The No Action Alternative and Alternative 1A(12) have low ranks (★) because they do not treat any contaminated sediment.

10.2.3 Short-term Effectiveness

This evaluation criterion addresses the effects of the alternatives on human health and the environment during the construction phase of the remedial action and until RAOs are achieved. This criterion includes the protection of workers and the community during construction, environmental impacts that result from construction, and the length of time until RAOs are achieved (Section 9.1.2.3).

10.2.3.1 Community and Worker Protection

This aspect of short-term effectiveness addresses impacts to human health from construction of the alternatives. Short-term impacts to both workers and the community are largely proportional to the length of the construction period (Table 10-1);[155] thus, longer construction periods are associated with greater relative impacts. In general, disruptions and inconveniences to the public and commercial community (e.g., increased street and vessel traffic, and potential temporary waterway restrictions) can be expected to increase with the duration of construction. Also, consumption of resident seafood that occurs during construction, despite the current WDOH advisory against consuming any such seafood, presents short-term risks to the community because concentrations of COCs in resident seafood are expected to remain elevated during and for some time after the period of construction as a result of contaminated sediment resuspension and biological uptake.

Local transportation impacts (e.g., traffic, noise, and air pollutant emissions) resulting from the implementation of the alternatives may affect the community. In this FS, these impacts are assumed to be proportional to the number of truck, train, and barge miles estimated for support of material hauling operations, both for the disposal of contaminated sediment and for the transportation of sand, gravel, armor stone, and activated carbon used in capping, ENR, backfilling of dredged areas, RMC, and in situ treatment. Table 10-1 summarizes estimates of truck, train, and barge miles under each alternative. Transportation-related impacts would be managed in part with traffic control plans developed during remedial design in consultation with affected stakeholders. All of the action alternatives have large impacts from truck, train, and barge miles due to the larger amounts (810,000 to 1,080,000 cy) of sediments being removed from the EW. Alternatives 1A(12), 1B(12), and 1C+(12) have the lowest transportation impacts from truck, train, and barge miles to remove 810,000 to 820,000 cy of sediment. Alternatives 2B(12), 2C+(12), 3B(12), and 3C+(12) have moderate transportation impacts due to removing 900,000 to 960,000 cy of sediment, and

[155] As described in Section 8.1.1.8, the Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15. However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15 (i.e., 100 days/season). It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15), the upper end of the number of work days in a construction season could increase to around 150 days/season, which could reduce the total number of years of construction by about 2 years, consistently across the action alternatives.

Alternatives 2C+(7.5) and 3E(7.5) have the largest transportation impacts due to removing 1,010,000 to 1,080,000 cy of sediment.

Activities on the construction site related to the operation of heavy equipment pose the greatest risk of physical accidents (injuries or fatalities). Risk to workers from exposure to site-related contaminants is generally low and is managed through established health and safety requirements for hazardous materials site work. Nevertheless, in both cases, the potential for exposure, injury, or fatality increases in proportion to the duration of construction activities, volume of material handled, and transportation requirements. Diver-assisted hydraulic dredging inherently has more risk for workers than any of the other construction activities, with risks for injury and death increasing with greater duration and amount of this activity. Safety concerns associated with diver-assisted hydraulic dredging used to address underpier areas for Alternatives 1C+(12), 2C+(12), 3C+(12), 2C+(7.5), and 3E(7.5) are proportional to the duration of this activity. Alternative 3E(7.5) poses the highest risk to worker safety because of the amount of hazardous diver-assisted hydraulic dredging included (12 construction years compared to 0 or 2 for other alternatives). Vessel navigation and berthing will also be restricted where construction activities are being conducted (e.g., sediment removal, material placement, and diving) to minimize the potential for accidents.

10.2.3.2 Environmental Impacts

Cleaning up the EW will have short-term environmental impacts that can be grouped into the categories of air pollutant emissions, landfill capacity utilization, depletion of natural resources, ecological impacts, and energy consumption. In general, longer duration alternatives and those with more removal have greater short-term impacts in all of these categories than similarly scaled alternatives that use more containment or ENR and MNR (see Table 10-1).

All alternatives except the No Action Alternative have similarly large remediation footprints, so the areal extent of short-term disturbances to the existing benthic community and other resident aquatic life is comparable. Due to dredging and capping activities during the construction phase, concentrations of bioaccumulative contaminants (e.g., total PCBs) are likely to remain elevated in the tissues of aquatic organisms, such as fish. Finally, damage or destruction of the benthic community would reduce food sources for other organisms until the biologically active zone is recolonized and the ecological functions are re-established.

Although BMPs (e.g., controls on dredge operations) will be used to minimize resuspension of contaminated sediment during dredging, some releases are an inevitable short-term impact. Resuspended material would resettle primarily on the dredged surface and in other areas outside of the dredge footprint. Dredging also releases contaminants into the water column. The impacts from resuspension increase relative to the amount of material dredged in each alternative. Adequate controls to manage dredge residuals that are deposited in the near-field (i.e., thin-layer sand placement as RMC) can be included in engineering design requirements and are an assumed element of the alternatives developed in this FS. Alternatives with more removal require more dredge residuals management actions than alternatives with more containment, ENR, and MNR.

Longer construction timeframes increase air pollutant emissions from construction equipment and noise. Air pollutant emissions include components with local environmental impacts (e.g., sulfur oxides or nitrogen oxides), those that can cause respiratory problems (e.g., PM_{10} and $PM_{2.5}$), and those with global impacts (e.g., carbon dioxide and other greenhouse gases). The primary source of air pollutant emissions is fuel consumption during construction activities. Transloading, transportation, and disposal of contaminated sediments account for the largest portion of the emissions, followed by emissions from material placement and dredging. The FS assumes that rail and barge transport will be used to the maximum extent possible. This is the most efficient way to reduce air pollutant emissions and will significantly reduce project air pollutant emissions as compared to long-haul trucking. Additional incremental reductions in air pollutant emissions may be possible by using BMPs during construction. Examples of BMPs that can be used to reduce emissions (e.g., use of biodiesel fuels) are discussed in Appendix I.

The alternatives consume quarry materials (e.g., sand, gravel, or armor stone) to satisfy the varying requirements for capping, backfilling (for habitat restoration), ENR, and RMC (Table 10-1). All alternatives have a similar total material placement volume (270,000 to 290,000 cy), although they vary in the use of that material (e.g., as capping material is reduced, RMC material increases).

All of the action alternatives greatly rely on dredging, and therefore consume landfill space proportional to the total removal volume (Table 10-1). Alternatives that include partial removal and ENR-nav/ENR-nav (i.e., Alternatives 1A(12), 1B(12), and 1C+(12)) consume less landfill space (810,000 to 820,000 cy removed from the waterway) than the other action alternatives (i.e., Alternatives 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5) and 3E(7.5); 900,000 to 1,080,000 cy removed from the waterway).

Energy required during the construction of the alternatives includes not only the energy consumed to remove sediment and dispose of it at a landfill, but also to transport and place all capping and in situ treatment materials at the EW. Alternative 3E(7.5) has the largest energy consumption because of its large removal volume, while Alternative 1A(12) has the lowest energy consumption because of its higher use of ENR and MNR. The other action alternatives have moderate energy consumption.

The carbon footprint is defined as the forested area necessary to absorb the carbon dioxide produced during the remedial activities for each alternative. This metric is dependent on the carbon dioxide emissions associated with generation of the energy needed to implement any alternative, and therefore the carbon footprint is proportional to energy consumption discussed in the preceding paragraph.

10.2.3.3 Time to Achieve RAOs

Table 10-1 presents the predicted times at which the alternatives achieve RAOs (based on start of construction as year 0 and taking into account the construction periods; see Section 9.1.2.3), as follows:

- **RAO 1:** All action alternatives are predicted to achieve the same order of magnitude cancer risk and non-cancer HQ. Alternative 1A(12) is predicted to achieve 1×10^{-5} order of magnitude cancer risk for Child Tribal RME in a longer timeframe than the other action alternatives (34 years from the start of construction), while the other action alternatives achieve it at the end of construction (9 to13 years, depending on the alternative). All of the action alternatives are predicted to achieve the other risk metrics at the end of construction (9 to13 years, depending on the alternative).

- **RAO 2:** All action alternatives are predicted to achieve the arsenic PRG both site-wide and in clamming areas at the end of construction. Model predictions indicate that arsenic concentrations in the EW could increase following construction, and maintaining the PRG in the long term is uncertain because of incoming sediment concentrations.
- **RAO 3:** Alternative 1A(12) is predicted to achieve the RAO 3 PRGs 39 years from the start of construction), while the other action alternatives are predicted to achieve it immediately after construction completion (9 to 13 years, depending on the alternative). The No Action Alternative is not expected to achieve the RAO 3 PRGs.
- **RAO 4:** The No Action Alternative is predicted to achieve RAO 4 PRGs at 10 and 25 years for English sole and brown rockfish, respectively, while all action alternatives are predicted to achieve RAO 4 PRGs after construction completion (9 to 13 years, depending on the alternative).

Overall, Alternatives 1B(12) and 1C+(12) are predicted to achieve RAOs 2 through 4 in 9 years, followed by Alternatives 2B(12), 2C+(12), 3B(12), and 3C+(12) in 10 years; 2C+(7.5) in 11 years; 3E(7.5) in 13 years; and 1A(12) in 9 years for RAOs 2 and 4 and 39 years for RAO 3. All action alternatives are predicted to meet similar risk thresholds for RAO 1 within 9 to 13 years except Alternative 1A(12), which is predicted to take 34 years to achieve similar child tribal risk thresholds.

As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years, consistently for all action alternatives, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in Section 9 and Table 10-1.

10.2.3.4 Summary of Short-term Effectiveness

For short-term effectiveness, the alternatives are ranked relative to each other, with five stars representing the most effective in the short-term, and one star representing the least effective in the short-term. The ranking balances the considerations discussed above, with the following three summary metrics considered equally: 1) community and worker protection during construction, which includes the duration of hazardous work (diver-assisted dredging); 2) environmental impacts from construction, including as a result of dredge releases, transportation, consumed landfill capacity, air emissions, energy consumption, and carbon footprint during implementation; and 3) the time to achieve RAOs (as a measure of the residual risk that is present on site until the RAOs are met).[156]

As shown in Table 10-1, the No Action Alternative has a low rank (⋆) because, although it has no impacts associated with construction (as no actions are included in its scope), it is not expected to achieve most of the RAOs. Alternative 3E(7.5) also ranks low (⋆) because it would: 1) have the greatest community and worker impact as it takes the longest to construct, and would have the highest potential for work-related accidents (due to 12 construction years of diver-assisted hydraulic dredging in underpier areas); 2) have the greatest environmental impacts as it consumes the greatest amount of energy and landfill space, generates the most transportation-related impacts, produces the most air pollutant emissions, has the largest carbon footprint, creates the longest periods of elevated bioaccumulation and exposure in resident species, and disturbs the largest surface area of benthic community and higher value habitat (i.e., shallower than -10 feet MLLW); and 3) has the longest time to achieve RAOs of the active alternatives. Alternative 1A(12) ranks relatively low (⋆⋆) because, although it has the lowest construction-related impacts of the action alternatives, it takes longer to achieve RAO 3 and 1 x 10^{-5} order of magnitude risk for Child Tribal RME, compared to the other action alternatives, due to some reliance on MNR. Alternative 2C+(7.5) also ranks low (★★) because of moderately more construction impacts compared to the action alternatives (11 years of construction; 2 years of diver-assisted hydraulic dredging) and moderately longer time to achieve RAOs (11 years). Alternatives 2C+(12) and 3C+(12) have a moderate ranking (★★★) due to the moderate construction impacts (10 years of construction, including 2 years of diver-assisted hydraulic dredging, and removal of 910,000 to 960,000 cy of sediment), and moderate time to achieve RAOs (following 10 years of construction). Alternatives 1C+(12), 2B(12), and 3B(12) are ranked relatively higher (★★★★) due to lower impacts to human health and the environment from construction activities, and having a moderately shorter time to achieve

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[156] Times to achieve RAOs could be reduced if a longer construction window is allowed, as the total number of years of construction could decrease by about 2 years, consistently for all action alternatives (see Section 9.1.2.3). However, the total number of construction days and associated construction impacts would remain unchanged.

RAOs (immediately post-construction). Alternative 1C+(12) requires 9 years of construction, 2 years of diver-assisted hydraulic dredging, and 820,000 cy of removal, and Alternatives 2B(12) and 3B(12) require more overall construction (10 years of construction and 900,000 or 960,000 cy of removal), but no diver-assisted hydraulic dredging. Alternative 1B(12) ranks highest (★★★★★) by having the least construction impacts among the alternatives (9 years of construction, no diver-assisted hydraulic dredging, 810,000 cy of removal), and achieving RAOs immediately following construction.

10.2.4 Implementability

Technical implementability, administrative implementability, and availability of services and materials are factors considered under this criterion (Section 9.1.2.4). Technical feasibility encompasses the complexity and uncertainties associated with implementation of the alternative, the reliability of the technologies, the ease of undertaking potential contingency remedial actions, and monitoring requirements. Administrative feasibility includes the activities required for coordination with other parties and agencies (e.g., consultation, obtaining permits for any off-site activities, or rights-of-way for construction). Availability of services and materials includes the availability of necessary equipment, materials, and specialists and the ability to obtain competitive bids for construction.

This implementability evaluation primarily focuses on the first two factors because the alternatives use the same types of technologies or the same types of equipment and methods, all of which are available and for which expertise exists in the Puget Sound region. The following sections discuss technical and administrative implementability during and following the construction phase of the project (i.e., in the long term), as summarized in Table 10-1. The No Action Alternative has no implementability challenges, while the action alternatives all represent large, complex remediation projects with many technical and administrative challenges.

10.2.4.1 Technical Implementability

The technical implementability challenges are similar across the action alternatives in open-water areas, but are different across these alternatives in underpier areas. The technical challenges associated with open-water dredging include the stability of structures adjacent to removal operations, managing controls during dredging (e.g., water quality criteria), and efficiently dewatering and transloading sediments. Technical challenges associated with capping include evaluating slope stability, constructing for scour mitigation, and cap placement and maintenance. Technical challenges for ENR are fewer than for dredging or capping and include predicting remedial performance when specifying material mixtures and thicknesses and accounting for physical and chemical interactions with existing sediments. Evaluating source control is a common technical challenge to all action alternatives.

The action alternatives vary widely in the degree of technical challenges for remediating underpier areas; few technical challenges for MNR (related to monitoring and potential contingency actions), moderate technical challenges for in situ treatment material placement, and the most technical challenges for diver-assisted hydraulic dredging. MNR, as part of Alternative 1A(12), has few technical challenges, with the lowest potential for difficulties and delays and impacts to EW tenants and users.

In situ treatment and diver-assisted hydraulic dredging in underpier areas have larger technical challenges than MNR. Alternatives 1B(12), 1C+(12), 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), and 3E(7.5) have either in situ treatment or both in situ treatment and diver-assisted hydraulic dredging in underpier areas.

For in situ treatment, selection of the treatment material depends on many site-specific chemical and physical factors that will require close consideration. Placement of in situ treatment material would be performed by conveyors, which is more complex than placement in open-water areas (see Section 8.1.2.1).

As discussed in Section 9.1.2.4, diver-assisted hydraulic dredging has the most technical challenges of any technology in underpier areas. This form of dredging is more difficult to implement than the other technologies, particularly in underpier areas of EW, where divers will be operating the dredge on steep slopes (1.75H:1V in most areas) composed of large riprap. Work will be conducted in deep water, which limits dive time for each diver and may require use of decompression chambers (as required by commercial diving regulations), resulting in a large team of divers to complete the work over a period of months and years. Technical challenges are also associated with low visibility as a result of shade from the pier, deeper water, and sediments suspended as part of the work, making the work more hazardous from a worker health and safety perspective. Debris, such as cables, large wood, and broken pilings, will also make dredging more difficult and potentially more risky. Technical challenges are also present with respect to infrastructure, such as existing piling and cross bracing, which will require relocation of both floating and submerged lines in and out of each bent.

Hydraulic dredging generates large quantities of slurry (sediment/water) that must be treated prior to discharge back to the waterway. Upland areas are not available for slurry storage, sediment settling, effluent treatment, testing, and discharge because of Port operations at existing terminals. Pipeline transport of the slurry to a single upland staging location is also not feasible because of impacts to navigation and long pipeline transport distances in the waterway. Therefore, it is most likely that the sediment slurry will need to be handled using a portable treatment system on a barge, which limits the daily production rate and complicates the staging, water containment, dewatering, and treatment.

Underpier areas are adjacent to active berthing areas. Use of berthing areas averages around 300 large container ships per year and 600 total vessel calls per year in the EW.[157] Placement of in situ treatment materials and diving schedules are likely to be significantly impacted by waterway activities, which could result in delays in completing the work. In particular, dive time may be further limited due to risks posed to divers from propwash and suction forces from transiting and berthing container vessels. Similarly, more business interruption will occur as a result of hydraulic dredging because of restricted access to areas where divers are performing underwater work. Alternatives 2C+(12), 3C+(12), and 2C+(7.5) employ diver-assisted hydraulic dredging followed by placement of in situ treatment material over limited areas, and Alternative 3E(7.5) employs diver-assisted hydraulic dredging over the entire underpier area exceeding RALs followed by placement of in situ treatment material.

[157] Total vessels include tugs, fuel barges, and other barges that are docking at Port facilities. The number does not include additional vessels that are not part of Port records (e.g., Olympic Tug and Barge activities).

10.2.4.2 Administrative Implementability

After construction, the alternatives vary in the potential for contingency actions related to maintaining the remedy in ENR, in situ treatment, and MNR areas. Although all of the alternatives rely primarily on dredging, Alternatives 1A(12), 1B(12), and 1C+(12) have more areas with potential future contingency actions (29 to 31 acres), Alternatives 2B(12), 2C+(12), 3B(12), 3C+(12), and 2C+(7.5) have some areas with potential future contingency actions, (11 to 15 acres), and Alternative 3E(7.5) has 1 acre of area with potential future contingency actions.

An administrative feasibility factor for the EW is that in-water construction is not allowed year-round in order to protect juvenile salmon and bull trout migrating through the EW. The in-water work window is estimated to be October 1 to February 15, a period that will be confirmed by EPA in consultation with the National Marine Fisheries Service and U.S. Fish and Wildlife Service before implementation. In addition, coordination is necessary with the tribes, Port tenants, and other waterway users to ensure that impacts to their activities are minimized during remediation because the EW is a busy working industrial waterway and used by tribes for a commercial salmon netfishery (see Section 8.1.1.8). This feasibility factor affects all the action alternatives similarly, generally proportional to the construction timeframe for the alternatives.

The action alternatives vary with respect to the need to reauthorize the federal navigation channel. Alternatives 1A(12), 1B(12), 1C+(12), 2B(12), 2C+(12), and 2B(7.5) include partial dredging and capping in the Shallow Main Body – South CMA, where the cap would be placed at elevations shallower than the current authorized elevation. Reauthorization from -34 to -30 feet MLLW is assumed for this FS to make some remedial actions feasible and appears to be a reasonable assumption based on current and anticipated future site use, but actual depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process. Another administrative challenge common to all action alternatives is associated with partial dredging and capping on state-owned aquatic land, which may be subject to DNR approval and a site use authorization.

10.2.4.3 Summary of Implementability

For implementability, the alternatives are ranked relative to each other, with five stars representing the most implementable, and one star representing the least implementable. The ranking considers two primary metrics equally: 1) technical implementability, with the key differentiating factor being the approach to remediating the technically challenging sediments under the piers; and 2) administrative implementability, with the key differentiating factor being the overall complexity of the cleanup which accounts for annual challenges of permitting, fisheries coordination, Port tenant and shipping vessel coordination, and staging. Contingency actions are also included in the ranking for implementability; however, this is considered a secondary metric that is weighted less in the overall ranking because contingency actions are potential conditions only.

The overall implementability rankings take into account all of the implementability considerations, but focus primarily on the key distinguishing components of the alternatives: the underpier technology employed and the overall scope of cleanup. Alternative 3E(7.5) receives the lowest rank (★) for implementability relative to the other alternatives, largely due to technical challenges associated with 12 construction years of diver-assisted hydraulic dredging over large areas of underpier sediment, placement of in situ treatment material under the piers, and the largest overall scope of the alternatives (13 years of construction). Alternatives 1C+(12), 2C+(12), 3C+(12), and 2C+(7.5) receive a relatively low ranking (★★) because they employ some diver-assisted hydraulic dredging followed by in situ treatment under the piers and have moderate overall scope of remediation (9 to 11 years). Alternatives 1B(12), 2B(12), and 3B(12) are considered moderately implementable (★★★) because they use in situ treatment in underpier areas and have moderate overall scope of remediation (9 to 11 years). Alternative 1A(12) scores highest among the action alternatives because of the high implementability of performing MNR under the piers (★★★★), and a moderately lower overall scope (9 years of construction). The No Action Alternative is given the highest implementability rank (★★★★★) because it has no construction elements and no provisions to trigger contingency actions.

10.2.5 Costs

This assessment evaluates the construction and non-construction costs of each alternative (Section 9.1.2.5). Detailed cost estimates for each alternative are presented in Appendix E and include assumptions for monitoring, project management, design, agency review and oversight, and contingency actions. Costs for contingency are included as a percentage of the construction costs (30%) to cover unknowns, unforeseen circumstances, and unanticipated conditions reducing the overall risk of cost overruns. Of this percentage, costs for potential contingency remedial actions are assumed to be needed in 15% of MNR, ENR, and in situ treatment areas. The estimates do not include anticipated costs for upland remediation or source control efforts. Total project costs for the alternatives are expressed in NPV and 2016 dollars and are assumed to be accurate within the range of -30% to +50%.

As discussed in Appendix E, the costs are very sensitive to the estimated dredge removal volume. Modest changes in dredge design factors (e.g., dredge footprint, depth of contamination, depth required for navigation clearance, side slope designs, or the amount of diver-assisted hydraulic dredging) can result in significant changes to dredge volumes and costs. Other factors, such as fuel and labor, can also significantly impact costs. The costs provided represent the best estimate of total costs for the proposed EW alternatives; however, several uncertainty factors discussed in Appendix E may affect the cost estimate and the actual cleanup costs.

The No Action Alternative is ranked five stars as the least expensive. The action alternatives are ranked relative to each other, with four stars representing the least expensive and one star representing the most expensive. The action alternatives are grouped based on ranges of costs using intervals of $30 million (i.e., $240 to $270 million, $270 to $300 million, and $300 to $330 million). Alternative 3E(7.5) has the highest cost ($411 million), and therefore ranks lowest (★) for this criterion. Alternatives 3C+(12) and 2C+(7.5) are assigned the next lowest rank (★★), with costs of $310 and $326 million, respectively. Alternatives 1C+(12), 2B(12), 2C+(12), and 3B(12) receive a moderate ranking (★★★) with costs from approximately $277 to $298 million. Alternatives 1A(12) and 1B(12) receive a high ranking (★★★★) with costs from approximately $256 and $264 million. The No Action Alternative has lowest cost, at $950,000, and has the highest ranking for cost (★★★★★).

10.3 Modifying Criteria – State, Tribal, and Community Acceptance

The community acceptance criterion refers to acceptance of EPA's preferred alternative in the ROD following the public comment period on EPA's Proposed Plan (Section 9.1.3). Therefore, Table 10-1 does not include alternative ranks for the state, tribal, and community acceptance criterion.

11 CONCLUSIONS

Cleanup of the EW is a complex, large-scale undertaking that seeks to accomplish important protections of human health and the environment in a challenging urban/industrial setting. This FS evaluated multiple factors to develop and compare a range of remedial alternatives for the EW that are protective over the long term. These factors include the following:

- Nature and extent of contamination, associated human health and environmental risks, and development of relevant RAOs and PRGs
- Applicability and limitations of the remedial technologies for areas within the EW OU
- Estimated short-term and long-term effectiveness of remedial alternatives, considering the effectiveness of remedial technologies and the physical/chemical factors, such as contaminant concentrations of incoming sediment and potential vessel scour

The National Research Council (NRC) published a report in 2007 on sediment cleanups at large Superfund sites that identifies similar challenges at sites elsewhere in the country and suggests how to move forward in selecting remedies for sites as large and complex as the EW. The report concludes with the following excerpt:

> *If there is one fact on which all would agree, it is that the selection and implementation of remedies at contaminated sediment sites are complicated. Many large and complex contaminated sediment sites will take years or even decades to remediate and the technical challenges and uncertainties of remediating aquatic environments are a major obstacle to cost-effective cleanup.*
>
> *Because of site-specific conditions—including hydrodynamic setting, bathymetry, bottom structure, distribution of contaminant concentrations and types, geographic scale, and remediation time frames—the remediation of contaminated sediment is neither simple nor quick, and the notion of a straightforward "remedial pipeline" that is typically used to describe the decision-making process for Superfund sites is likely to be at best not useful and at worst counterproductive.*

> *The typical Superfund remedy-selection approach, in which site studies in the remedial investigation and feasibility study establish a single path to remediation in the record of decision, is not the best approach to remedy selection and implementation at these sites owing to the inherent uncertainties in remedy effectiveness. At the largest sites, the time frames and scales are in many ways unprecedented. Given that remedies are estimated to take years or decades to implement and even longer to achieve cleanup goals, there is the potential—indeed almost a certainty—that there will be a need for changes, whether in response to new knowledge about site conditions, to changes in site conditions from extreme storms or flooding, or to advances in technology (such as improved dredge or cap design or in situ treatments). Regulators and others will need to adapt continually to evolving conditions and environmental responses that cannot be foreseen.*
>
> *These possibilities reiterate the importance of phased, adaptive approaches for sediment management at megasites. As described previously, adaptive management does not postpone action, but rather supports action in the face of limited scientific knowledge and the complexities and unpredictable behavior of large ecosystems.* (NRC 2007)

In that context, Section 11.1 discusses key conclusions related to protecting human health and the environment by comparing the remedial alternatives with respect to their compliance with CERCLA criteria. Risk management principles and national guidance are discussed in Section 11.2. Section 11.3 briefly describes the uncertainties associated with the alternatives and their predicted outcomes. Finally, Section 11.4 discusses the next steps in the process for selecting the remedy for the EW.

11.1 Summary of the Comparative Analysis

The remedial alternatives were evaluated using seven of the nine CERCLA criteria, which include two threshold criteria and five balancing criteria. The two threshold criteria, which must be met before the others can be considered, are:

- Overall protection of human health and the environment
- Compliance with ARARs of federal and state environmental laws and regulations

The five balancing criteria are:

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost

The two modifying criteria, state/tribal and community acceptance, were not evaluated at this time. EPA will evaluate state, tribal, and community acceptance of the selected remedial action in the ROD following the public comment period on EPA's Proposed Plan.

Figure 11-1 presents a summary of the comparative analysis under the CERCLA evaluation criteria. The No Action Alternative failed to meet CERCLA threshold criteria, but was retained as a basis to compare the relative effectiveness of the other alternatives. A high ranking (dark green dot) means that the alternative ranks high compared to other alternatives, whereas a low ranking (red dot) means the alternative ranks low compared to other alternatives. In some cases, the evaluation did not identify substantial differences among the alternatives and, therefore, the rankings are the same for those criteria.

Table 11-1 summarizes key factors considered in the comparison of the alternatives. The following sections discuss these key factors, organized by the two threshold and five balancing criteria under CERCLA.

11.1.1 Overall Protection of Human Health and the Environment

Assessment of overall protection of human health and the environment primarily draws on evaluation of long-term effectiveness and short-term effectiveness. All of the action alternatives (Alternatives 1A(12) through 3E(7.5)) meet the threshold requirement of overall protection of human health and the environment by reducing risks to human health and environment for each of the RAOs during and following construction.

Table 11-1
Summary of Comparative Evaluation of Alternatives

Evaluation Criteria			Alternative									
			No Action	**1A(12)**	**1B(12)**	**1C+(12)**	**2B(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**2C+(7.5)**	**3E(7.5)**
Threshold Criteria												
Overall Protection of Human Health and the Environment												
Magnitude and Type of Residual Risk	RAO 1 – Human Health (Seafood Consumption) [a]	Total PCBs and Dioxins/Furans	Does not achieve.	The action alternatives are predicted to achieve total excess cancer risks of 2 to 3 × 10^{-4} (Adult Tribal RME), 4 to 5 × 10^{-5} (Child Tribal RME), and 1 x 10^{-4} to 9 × 10^{-5} (Adult API RME). The alternatives are also predicted to achieve total PCBs non-cancer risks (based on immunological, integumentary, or neurological endpoints only, which are the highest of the non-cancer risks) of HQ = 4 to 5 (Adult Tribal RME), HQ = 9 to 12 (Child Tribal RME), and HQ = 4 to 5 (Adult API RME).								
	RAO 2 – Human Health (Direct Contact)	Arsenic	All alternatives are predicted to achieve a total excess cancer risk less than 1 × 10^{-5}. For arsenic, all action alternatives achieve individual excess cancer risk of 2 x 10^{-6} for netfishing and 7 x 10^{-6} for clamming. Because the target risk threshold for arsenic is below natural background, the PRG is also used as a comparison; all action alternatives are predicted to meet the natural background-based PRG following construction, but increase above the PRGs in the long term, due to incoming Green River concentrations. The No Action Alternative is not predicted to meet the arsenic PRG.									
	RAO 3 – Ecological Health (Benthic Organisms)	29 COCs[b]	Not expected to achieve.	Alternative 1A(12) is predicted to meet benthic PRGs in 99% of point locations 40 years following construction.	Alternatives 1B(12) through 3E(7.5) are predicted to meet benthic PRGs in 100% of point locations after construction completion.							
	RAO 4 – Ecological Health (Fish)	Total PCBs	HQ > 1.0 using the lower LOAEL TRV; HQ ≤ 1.0 using the higher LOAEL TRV.	All action alternatives are predicted to achieve HQ ≤ 1.0 for English sole and HQs ≤ 1.0 for brown rockfish for the higher LOAEL TRV and 1.1 to 1.3 for the lower LOAEL TRV (assumptions regarding water concentrations result in HQs slightly above 1.0) at year 40 following construction.								
Compliance with ARARs												
MTCA/SMS			Not expected to comply for RAOs 1 and 3.	All action alternatives are predicted to achieve PRGs or risk targets for RAOs 2 through 4. For RAO 1, the action alternatives are not likely to meet all natural background-based PRGs. If EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs, EPA may adjust the cleanup level upward to the CSL, which could be attained in a reasonable restoration timeframe, consistent with the substantive requirements of SMS (see Sections 4.3.1 and 9.1.1.2), or waive the ARAR on the basis of technical impracticability in a future decision document (ROD Amendment or ESD).								
Surface Water Quality Standards			No active remedial measures are technically feasible or anticipated expressly for the water column, although water quality improvements are anticipated from sediment remediation and additional source control measures. It is not anticipated that any alternative can comply with all federal or state ambient water quality criteria or standards, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain (e.g., total PCBs and arsenic). If long-term monitoring data and trends indicate that water quality ARARs cannot be met, EPA will determine whether further remedial action could practicably achieve the ARAR. If EPA concludes that an ARAR cannot be practicably achieved, EPA may waive the ARAR on the basis of technical impracticability in a future decision document (ROD Amendment or ESD).									
Achieve Threshold Criteria?			**No**	**Yes; however, one or more ARAR waivers may be required.**								
Balancing Criteria												
Long-term Effectiveness and Permanence												
Long-term Risk Outcomes			Does not achieve all.	See the risk outcomes for Magnitude and Type of Residual Risk above. The action alternatives achieve similar risk outcomes with Alternative 1A(12) having slightly higher risks.								
Technology Areas (acres; of 157 acres in the EW)	Most permanent: Removal		No controls assumed.	77	77	79	94	94	100	100	104	111
	Highly permanent: partial dredging and capping			13	13	13	13	13	7	7	13	7
	Moderately permanent: in situ treatment			0	12	12	12	12	12	12	13	13
	Less permanent: ENR-nav, ENR-sill, MNR			31	19	19	3	3	1	1	3	1
Ranking[c] for long-term effectiveness and permanence			★	★★★	★★★★	★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★

Table 11-1
Summary of Comparative Evaluation of Alternatives

Evaluation Criteria		Alternative: No Action	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Reduction of Toxicity, Mobility, or Volume Through Treatment											
Ranking[d] for reduction of toxicity, mobility, or volume through treatment		★	★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
Short-term Effectiveness											
Impacts During Construction	Period of effects to human health and the environment (construction timeframe; years)[e]	n/a	9	9	9	10	10	10	10	11	13
	Diver-assisted dredging (hazardous work duration; diver years)	n/a	n/a	n/a	2	n/a	2	n/a	2	2	12
	Total removal volume / Consumed landfill capacity (cy)[f]	n/a	810,000 / 970,000	810,000 / 970,000	820,000 / 980,000	900,000 / 1,080,000	910,000 / 1,090,000	960,000 / 1,150,000	960,000 / 1,150,000	1,010,000 / 1,210,000	1,080,000 / 1,300,000
	Air quality impacts (CO_2 / PM_{10} emissions; metric tons)	n/a	16,000 / 5.4	16,000 / 5.6	16,000 / 5.9	17,000 / 6.1	18,000 / 6.3	18,000 / 6.4	18,000 / 6.6	19,000 / 7.0	23,000 / 8.3
	Carbon footprint (acre-years)[g]	n/a	3,800	3,800	3,800	4,000	4,300	4,300	4,300	4,500	5,400
Time to Achieve RAOs (years from start of construction)[h]	Human Health – Seafood Consumption (RAO 1 – Risk Ranges)[i]	Does not achieve.	34	9	9	10	10	10	10	11	13
	Human Health – Direct Contact (RAO 2)	Does not achieve.	9	9	9	10	10	10	10	11	13
	Ecological Health – Benthic Organisms (RAO 3)	Not expected to achieve.	39[j]	9	9	10	10	10	10	11	13
	Ecological Health – Fish (RAO 4)	25	9	9	9	10	10	10	10	11	13
Ranking[k] for short-term effectiveness		★	★★	★★★★★	★★★★	★★★★	★★★	★★★★	★★★	★★	★
Implementability											
Ranking[l] for implementability		★★★★★	★★★★	★★★	★★	★★★	★★	★★★	★★	★★	★
Costs											
Total Costs		$950,000	$256,000,000	$264,000,000	$277,000,000	$284,000,000	$297,000,000	$298,000,000	$310,000,000	$326,000,000	$411,000,000
Ranking[m] for costs		★★★★★	★★★★	★★★★	★★★	★★★	★★★	★★★	★★	★★	★

Notes:

a. See Tables 9-5a and 9-5b for other RME risk scenarios.

b. For FS purposes, achievement of RAO 3 is based on at least 98% of predicted surface sediment locations achieving PRGs for all 29 benthic COCs. Compliance with SMS benthic criteria will be determined based on SMS requirements. Predictive modeling was not conducted on all chemicals for the No Action Alternative for compliance of RAO 3. However, it was predicted to exceed for some of those evaluated; therefore, the percentage of surface sediment locations below PRGs are presented for existing conditions (see Table 9-3).

c. The alternatives are ranked relative to other alternatives, with five stars representing the most effective in the long term and most permanent, and one star representing the least effective in the long term and least permanent. The ranking considers the metrics above, summarized as the following two that are considered equally: 1) the magnitude and type of residual risk remaining in the long term, including the risk outcomes and the area with remaining subsurface contamination; and 2) adequacy and reliability of engineering controls, considering the area with remaining contamination on site that will require monitoring and maintenance.

d. The alternatives are ranked relative to the total remediation area in the waterway, with five stars representing use of extensive in situ treatment among the alternatives, and one star representing no use of in situ treatment. Although none of the alternatives employ in situ treatment extensively in the waterway, the highest-ranked alternative is given five stars.

e. Construction timeframe rounded up to the nearest year, and assumes some concurrent removal and material placement (see Table 8-6 for details). As described in Section 8.1.1.8, the Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15. However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15 (i.e., 100 days/season). It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15); thus, the upper end of the number of work days in a construction season could increase to around 150 days/season, reducing the total number of years of construction by 2 years, consistently for all action alternatives.

f. The landfill capacity consumed is proportional to the volume of dredged material removed and disposed of in the landfill (assuming a 20% bulking factor).

g. One acre-year represents the amount of CO_2 sequestered by 1 acre of Douglas fir forest for 1 year. Carbon footprint in units of acre-years is appropriate to compare the alternatives differences in CO_2 releases over the entire project.

h. The longest time to achieve among the metrics for four RAOs is presented in this table (see Table 10-1 for detailed times to achieve each RAO). Time to achieve RAOs is based on attaining the PRGs or target risk thresholds, as applicable. Times to achieve RAOs could be reduced if a longer construction window is allowed, as the total number of years of construction could decrease by 2 years, consistently among the action alternatives (see Section 9.1.2.3).

i. Long-term modeling results predict that none of the alternatives will achieve the RAO 1 natural background-based PRG for total PCBs and dioxins/furans. To differentiate among the alternatives, achieving 1×10^{-4} cancer risk for the Adult Tribal RME, 1×10^{-5} cancer risk for the Child Tribal RME, and 1×10^{-4} and 1×10^{-5} cancer risk for the API RME are used as risk reduction milestones for the time to achieve RAO 1 for these two risk driver COCs (see Section 9.1.2.3).
j. Time to achieve RAO 3 PRG based on total PCBs; all other benthic risk driver COCs achieve PRGs immediately after construction completion.
k. The alternatives are ranked relative to each other, with five stars representing the most effective in the short term, and one star representing the least effective in the short term. The ranking considers the metrics above, summarized as the following three categories, which are considered in equal proportion: 1) community and worker protection during construction, which includes the duration of hazardous work (diver-assisted dredging); 2) environmental impacts from construction, including as a result of dredge releases, transportation, consumed landfill capacity, air emissions, energy consumption, and carbon footprint during implementation; and 3) the time to achieve RAOs (as a measure of the residual risk that is present on site until the RAOs are met).
l. The alternatives are ranked relative to each other, with five stars representing the most implementable, and one star representing the least implementable. The ranking considers the following primary metrics equally: 1) technical implementability, with the key differentiating factor being the approach to remediating the technically challenging sediments under the piers; and 2) administrative implementability, with a key differentiating factor being the overall scope of cleanup, which accounts for annual challenges with permitting, fisheries coordination, Port tenant and shipping vessel coordination, and staging.
m. The No Action Alternative is ranked five stars as the least expensive. The action alternatives are ranked relative to each other, with four stars representing the least expensive, and one star representing the most expensive. The action alternatives are grouped based on ranges of costs, using intervals of $30 million each (i.e., $240 to $270 million, $270 to $300 million, $300 to $330 million, and more than $330 million).

Abbreviations:

API – Asian Pacific Islander
ARAR – applicable or relevant and appropriate requirements
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
CO_2 – carbon dioxide
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
cy – cubic yards
ENR-nav – enhanced natural recovery used in the navigation channel or berthing areas
ENR-sill – enhanced natural recovery used in the sill reach
EPA – U.S. Environmental Protection Agency
ESD – Explanation of Significant Differences
EW – East Waterway
FS – Feasibility Study
HQ – hazard quotient
LOAEL – lowest-observed-adverse-effect level
MNR – monitored natural recovery
MTCA – Model Toxics Control Act
n/a – not applicable
PCB – polychlorinated biphenyl
PM_{10} – particulate matter less than 10 microns in diameter
PRG – preliminary remediation goal
RAO – remedial action objective
RME – reasonable maximum exposure
ROD – Record of Decision
SMS – Washington State Sediment Management Standards
TRV – toxicity reference value

In the long term, the action alternatives achieve significant risk reduction by relying primarily on removal of contaminated sediment from the EW and using other reliable active remedial technologies, coupled with monitoring and institutional controls to measure and verify long-term risk reduction. The action alternatives are all predicted to achieve PRGs or risk thresholds for RAO 2, 3, and 4. Although none of the action alternatives are predicted to achieve the natural background-based PRGs for RAO 1 for total PCBs or dioxins/furans, all action alternatives are predicted to achieve a similar order of magnitude of risks. For example, 40 years after construction completion, all action alternatives are predicted to achieve a residual total excess cancer risk of 2 or 3×10^{-4} for the Adult Tribal seafood consumption RME scenario, 4 or 5×10^{-5} for the Child Tribal seafood consumption RME scenario, and 1×10^{-4} or 9×10^{-5} for the Adult API seafood consumption RME scenario (see Table 11-1). The No Action Alternative is predicted to achieve RAO 4, but not RAOs 1, 2, or 3.

For RAO 2, all alternatives are predicted to achieve a total excess cancer risk of less than 1×10^{-5}. For arsenic, the action alternatives are predicted to meet the natural-background-based PRG following construction, but increase above the PRG in the long term due to incoming Green River concentrations. The No Action Alternative is not predicted to meet the arsenic PRG.

For RAO 3, the No Action Alternative is not expected to achieve the benthic PRGs. Alternative 1A(12) is predicted to meet benthic PRGs in 99% of point locations 40 years following construction. Alternatives 1B(12) through 3E(7.5) are predicted to meet benthic PRGs in 100% of point locations after construction completion.

For RAO 4, the No Action Alternative does not achieve an HQ less than 1.0 using the lower LOAEL TRV, but does achieve an HQ less than 1.0 using the higher LOAEL TRV. The No Action Alternative is predicted to meet both PRGs within 25 years. All action alternatives are predicted to achieve an HQ less than 1.0 for English sole (using either LOAEL TRV) and for brown rockfish (using the higher LOAEL TRV). An HQ ranging from 1.0 to 1.3 for brown rockfish is achieved using the lower LOAEL TRV (the HQ is greater than 1.0 because of the influence of receiving water PCB concentrations). All action alternatives are predicted to meet the PRGs following construction.

The evaluation of overall protectiveness for short-term effectiveness includes the effects of the alternatives on human health and the environment during the construction phase (the time required to implement the remedy) of the remedial action and the time until RAOs are achieved. Alternatives with larger total sediment removal volumes and longer construction timeframes present proportionately larger impacts to workers, the community, and the environment during implementation. In addition, longer construction periods increase traffic, potential for worker injuries/fatalities, dredge material resuspension and releases, air pollutant emissions, noise, natural resource use, physical disruption of aquatic habitat, and elevated fish and shellfish tissue contaminant concentrations (see Section 10.2.3). In general, the impacts from construction are greatest for dredging, relatively high for capping, and significantly reduced for ENR, in situ treatment, and MNR. Predicted impacts due to construction are generally considered proportional to construction timeframe for the remedial alternatives; however, short-term impacts to workers are expected to be larger for alternatives with diver-assisted hydraulic dredging due to the significant hazards associated with underpier, deep water work. The action alternatives range from 9 to 13 years to construct due to the large scope of dredging for all alternatives—with Alternative 3E(7.5) having the greatest short-term impacts to workers due to the considerable diver-assisted hydraulic dredging in underpier locations, which has intrinsically high safety concerns.

Figure 11-2 presents the summary of model-predicted times to achieve evaluation metrics for the four RAOs for the alternatives. While the No Action Alternative is not predicted to achieve all RAOs, all of the action alternatives are predicted to achieve RAOs. The action alternatives are predicted to achieve PRGs for RAOs 2 through 4 immediately following construction, with the exception of Alternative 1A(12), which is predicted to achieve RAO 3 in 39 years from the start of construction. In addition, all of the action alternatives achieve similar risk reductions for RAO 1, and the time to achieve RAO 1 is expected to be similar for any of the action alternatives.

11.1.2 Compliance with ARARs

Two key ARARs for the EW cleanup are the Washington State SMS (WAC 173-204), which are implemented under MTCA to define how sediment sites meet MTCA, and federal recommended and state surface water quality criteria and standards.

Part V of the SMS (WAC 173-204) is promulgated under MTCA and establishes requirements for remediation of contaminated sediment. The nine action alternatives have been developed in this FS to be compliant with SMS. In particular, SMS (WAC 173-204-560) provides rules for developing cleanup levels considering multiple exposure pathways, background concentrations, and PQLs. The PRGs for RAO 1 for total PCBs and dioxins/furans were developed to be consistent with the rules for cleanup level determination in SMS, but without considering regional background, as it has not been defined for this area (see Appendix A for additional details). All of the action alternatives are expected to comply with MTCA/SMS standards for protectiveness of human health for direct contact (RAO 2), protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs or target risk levels for these RAOs, through active remediation, and additional MNR for Alternative 1A(12) only.

For protection of human health for seafood consumption (RAO 1), none of the action alternatives are predicted to achieve the natural background PRGs for PCBs or dioxins/furans, due to model input parameters that assume ongoing contribution of contaminants from diffuse nonpoint sources upstream of the EW. Although the SMS allows for use of a regional background-based cleanup level if it is not technically possible to meet and maintain natural background levels, regional background levels have not yet been established for the geographic area of the EW.

However, CERCLA compliance with MTCA/SMS ARARs may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are much lower than current model predictions, and PRGs identified in this FS are attained in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or

ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

All of the alternatives must comply substantively with relevant and appropriate state water quality standards and any more stringent recommended federal surface water quality criteria upon completion of the remedial action, except to the extent that they may be formally waived by EPA. While significant water quality improvements are anticipated from sediment remediation and additional source control measures, current upstream Green River and downstream Elliott Bay water concentrations appear to be above federal recommended water quality criteria for some chemicals, and therefore, it is not technically practicable for any alternative to meet all human health federal recommended or state ambient water quality criteria or standards, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain (e.g., total PCBs and arsenic). If long-term monitoring data and trends indicate that water quality ARARs cannot be met, EPA will determine whether further remedial action could practicably achieve the ARAR. If EPA concludes that an ARAR cannot be practicably achieved, EPA may waive the ARAR on the basis of TI in a future decision document (ROD Amendment or ESD).

11.1.3 Long-term Effectiveness and Permanence

This balancing criterion compares the relative magnitude and type of residual risk that would remain in the EW after remediation under each alternative. In addition, it assesses the extent and effectiveness of the controls that may be required to manage the residual risks from contamination remaining at the site after remediation (see Section 9.1.2.1).

The magnitude of residual risk in surface sediment is the risk predicted to remain on site from exposure to surface sediment contaminant concentrations after the completion of remediation and over time. It was assessed by comparing the predicted outcomes of the alternatives relative to the RAOs. All of the action alternatives are predicted to achieve PRGs (or risk thresholds) for RAOs 2 through 4. For RAO 1, the action alternatives achieve similar risk reductions.

Residual risks were also evaluated from contaminated sediments remaining in the subsurface after remediation (e.g., under caps or in areas remediated by ENR-nav, ENR-sill, in situ treatment, or MNR), which may be exposed in the future through disturbance. All of the action alternatives emphasize removal of contaminated sediments for the majority of the waterway, and thus, have a low potential for subsurface sediment to be exposed. They all include monitoring, maintenance, institutional controls, periodic reviews (e.g., every 5 years), and potential contingency actions to maintain effectiveness over the long term. The subsurface contaminated sediments remaining in place in capped areas have a low potential for exposure because caps are engineered to remain structurally stable under location-specific conditions and provide a high degree of protectiveness. In the context of long-term effectiveness and permanence, the differences among these alternatives are primarily related to the remedial technologies used. In the limited areas that rely on ENR-nav, ENR-sill, in situ treatment, and MNR, residual contaminated sediment has a greater potential for future exposure, as a result of disturbance, and could require more monitoring and potential maintenance, and adaptive management of these areas would trigger contingency actions. In situ treatment is considered more permanent than partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR because in situ treatment permanently binds and reduces the bioavailability of hydrophobic organic compounds (e.g., PCBs) by an estimated 70% (see Section 7.2.7.1). Proposed in situ treatment, partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR areas also represent a relatively small contribution (less than 20%) to the overall EW remedial footprint for alternatives. Removal through diver-assisted hydraulic dredging in underpier areas is also likely to leave contaminated sediment behind due to the presence of riprap slopes and debris.

For long-term effectiveness and permanence, the alternatives are ranked relative to other alternatives, with five stars representing the most effective in the long term and most permanent, and one star representing the least effective in the long term and least permanent. The ranking considers both factors described above, equally: 1) risk reduction achieved by the alternative in the long term and magnitude and type of residual risk remaining; and 2) adequacy and reliability of engineering controls, considering the area of the waterway with contamination permanently removed, and the area with remaining contamination that will require technology-specific monitoring and maintenance, beyond site-wide monitoring.

As shown in Table 11-1, the No Action Alternative ranks the lowest among all alternatives (★) for long-term effectiveness and permanence because it would not reduce risks sufficiently to achieve any of the RAOs, it would leave the largest amount of subsurface contamination in place, and it would not provide reliable controls. All of the action alternatives are considered highly permanent due to a primary reliance on removal (between 80% and 99% of the remediation area undergoes removal or partial removal). Alternative 1A(12) ranks moderate (★★★) because it removes the least amount of contaminated sediment among the action alternatives, has slightly higher residual risks in the long term (due to reliance on MNR), and would leave the largest area without engineering controls (13 acres in underpier areas) to be managed by MNR (the more uncertain technology for underpier); therefore, requiring more intensive monitoring and maintenance and potential contingency actions in the future. Alternatives 1B(12) and 1C+(12) rank relatively higher (★★★★) because they achieve slightly lower risks than Alternative 1A(12) but would remove a similar amount of contaminated sediment as Alternative 1A(12) and have a larger area managed by ENR and in situ treatment. Alternatives 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), and 3E(7.5) rank highest (★★★★★) because they achieve similar risks as other active alternatives, and they rely more on removal than Alternatives 1B(12) and 1C+(12), and are therefore likely to be more permanent. All alternatives include little ENR and limited areas of engineered isolation capping, which is considered highly permanent.

11.1.4 Reductions in Mobility, Toxicity, or Volume through Treatment

This criterion assesses the degree to which site media are treated to permanently and significantly reduce the toxicity, mobility, or volume of site contaminants. The only treatment technology retained for the remedial alternatives is in situ treatment using activated carbon. Activated carbon lowers the mobility of contaminants,[158] reducing the toxicity and bioavailability to biological receptors directly in areas where it is applied and indirectly site-wide through reduced releases to the water column, which lowers average exposure to receptors.

For FS comparison purposes, the reduction of mobility achieved by in situ treatment is proportional to the area that undergoes treatment. The alternatives are ranked relative to each other, with those alternatives with the use of extensive in situ treatment among the alternatives (e.g., > 10 acres) receiving five stars, and alternatives with no in situ treatment receiving one star. As shown in Table 11-1, although none of the alternatives have extensive use of in situ treatment throughout the waterway, Alternatives 1B(12), 1C+(12), 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), and 3E(7.5) employ in situ treatment in underpier areas above RALs (varying from 12 to 13 acres) and therefore rank the highest (★★★★★) for this balancing criterion. The No Action Alternative and Alternative 1A(12) have low ranks (★) because they do not treat any contaminated sediment.

11.1.5 Short-term Effectiveness

The evaluation of short-term effectiveness includes the effects of the alternatives on human health and the environment during the construction phase of the remedial action and the time until RAOs are achieved (see Table 11-1 and Figure 11-2). Alternatives with larger removal volumes and longer construction timeframes (particularly alternatives with diver-assisted hydraulic dredging) present proportionately larger risks to workers, the community, and the environment. Longer construction periods increase traffic, potential for worker injuries/fatalities, dredge material resuspension and releases, air pollutant emissions, noise, carbon footprint, consumed landfill capacity, physical disruption of aquatic habitat, and elevated fish and shellfish tissue contaminant concentrations. The construction periods for

[158] Activated carbon (AC) has been demonstrated to reduce the bioavailability of several contaminants, including PAHs, PCBs, dioxins/furans, DDT, and mercury. For the purpose of modeling, this FS assumes that in situ treatment with AC will reduce bioavailability for hydrophobic organic compounds (e.g., total PCBs, cPAHs, and dioxins/furans) by an estimated 70%, consistent with values measured in the field and laboratory and considering material stability, when applying an AC dose between 3% and 5% (see Section 7.2.7.1).

the action alternatives vary from 9 to 13 years[159]—with Alternative 3E(7.5) having the greatest risks to workers than any of the other alternatives due to the longest overall construction timeframe and considerable duration of underwater removal using divers in underpier areas (12 construction years compared to 0 or 2 years for other action alternatives).

The time to achieve RAOs 2[160] through 4 is equal to the construction duration for all of the action alternatives except Alternative 1A(12), which meets RAO 3 in 39 years from the start of construction. The action alternatives do not achieve PRGs for total PCBs and dioxins/furans for RAO 1, but achieve similar risk reductions. Alternative 1A(12) is predicted to achieve 1 x 10^{-5} order of magnitude cancer risk for Child Tribal RME in a longer timeframe than the other action alternatives (34 years from the start of construction), while the other action alternatives achieve it at the end of construction (9 to 13 years, depending on the alternative). Other RAO 1 risk metrics are predicted to be achieved at the same time by all action alternatives (9 to 13 years, depending on the alternative). The No Action Alternative is predicted to achieve RAO 4 (at year 25), but not RAOs 1, 2, or 3.

For short-term effectiveness, the alternatives are ranked relative to each other, with five stars representing the most effective in the short-term, and one star representing the least effective in the short-term. The ranking balances the considerations discussed above, with the following three summary metrics considered equally: 1) community and worker protection during construction, which includes the duration of hazardous work (diver-assisted dredging); 2) environmental impacts from construction, including as a result of dredge releases, transportation, consumed landfill capacity, air emissions, energy

[159] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years, consistently across the action alternatives, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented here.

[160] Achievement of RAO 2 is based on meeting the PRG for arsenic. All action alternatives are predicted to meet the arsenic RAO 2 PRG of 7 mg/kg dw following construction, but increase above the PRG, due to the incoming Green River concentrations (Section 9.15.1.2). All alternatives, including the No Action Alternative, may meet the PRG in the long term, depending on actual site conditions.

consumption, and carbon footprint during implementation; and 3) the time to achieve RAOs (as a measure of the residual risk that is present on site until the RAOs are met).[161]

As shown in Table 11-1, the No Action Alternative has the lowest ranking (★) for short-term effectiveness because, although it has no impacts associated with construction (as no actions are included in its scope), it is not expected to achieve most of the RAOs. Alternative 3E(7.5) also ranks the lowest (★) because it has: 1) the greatest short-term impacts to human health and the environment during construction, due to the amount of sediment removal (and associated long construction timeframe); 2) the highest potential for work-related accidents (due to extensive use of diver-assisted hydraulic dredging [12 construction years] in underpier areas), which poses substantial health and safety risks to remediation workers; and 3) the longest time to achieve RAOs among the active alternatives. Alternative 1A(12) ranks relatively low (★★) because, although it has the lowest construction-related impacts of the action alternatives, it takes longer to achieve RAO 3 and the 1 x 10^{-5} order of magnitude risk for Child Tribal RME, compared to the other action alternatives, due to some reliance on MNR. Alternative 2C+(7.5) also ranks relatively low (★★) because of moderately more construction impacts compared to the action alternatives (11 years of construction and 2 years of diver-assisted hydraulic dredging) and moderately longer time to achieve RAOs (11 years). Alternatives 2C+(12) and 3C+(12) have a moderate ranking (★★★) due to the moderate construction impacts to human health and the environment (10 years of construction, including 2 years of diver-assisted hydraulic dredging, and removal of 910,000 and 960,000 cy of sediment), and moderate time to achieve RAOs (following 10 years of construction). Alternatives 1C+(12), 2B(12) and 3B(12) are ranked relatively higher (★★★★) due to lower construction impacts to human health and the environment (by requiring 10 years of construction and no diver-assisted hydraulic dredging, and removal of 900,000 to 960,000 cy of sediment from the waterway), and having a moderately shorter time to achieve RAOs (immediately post-construction). Alternative 1C+(12) also scores relatively higher (★★★★) by having a shorter construction timeframe (9 years), removing less total sediment (820,000 cy), and having a shorter time to achieve RAOs (9 years), but also includes 2 years

[161] Times to achieve RAOs could be reduced if a longer construction window is allowed, as the total number of years of construction could decrease by about 2 years, consistently across the action alternatives (Section 9.1.2.3). However, the total number of construction days and associated construction impacts would remain unchanged.

of diver-assisted hydraulic dredging. Alternative 1B(12) ranks highest (★★★★★) by having the least construction impacts among the alternatives (9 years of construction, no diver-assisted hydraulic dredging, and removal of 810,000 cy of sediment), and achieving RAOs immediately following construction.

11.1.6 Implementability

Technical implementability and administrative implementability are factors considered under this criterion for the EW OU. Technical implementability encompasses the complexity and uncertainties associated with the alternative, the reliability of the technologies, the ease of undertaking potential contingency remedial actions, and monitoring requirements. Administrative implementability includes the activities required for coordination with other parties and agencies (e.g., consultation, or obtaining permits for construction activities). The No Action Alternative has no implementability challenges, while the action alternatives represent large, complex remediation projects with many technical and administrative challenges.

The technical implementability challenges are similar across the action alternatives in open-water areas, but are different across these alternatives in underpier areas. Alternative 1A(12) has few technical challenges associated with MNR in underpier areas (only those related to monitoring and potential contingency actions) and low potential for difficulties and delays and impacts to EW tenants and users. The other action alternatives have moderate technical challenges associated with placing in situ treatment material in underpier areas. Alternatives 2C+(12), 3C+(12), 2C+(7.5), and 3E(7.5) have large technical challenges associated with diver-assisted hydraulic dredging under piers. This form of dredging is more difficult to implement than the other technologies, particularly in underpier areas of EW, due to work conducted in deep water with low visibility and presence of suspended sediments, variable conditions under piers (e.g., presence of debris, cables, large wood, and broken pilings), potential prolonged impacts and delays to vessel operations (related to diving schedules), extensive dewatering requirements, and water management operations.

For administrative implementability, all underpier technologies (MNR, in situ treatment, and diver-assisted hydraulic dredging) will be monitored following construction and have the possibility for future contingency actions if remediation goals are not met. In addition, Alternatives 1A(12), 1B(12), and 1C+(12) have a higher potential for future contingency actions in open-water areas because of ENR-nav in the navigation channel.

An administrative feasibility factor for the EW is that in-water construction is not allowed year-round, in order to protect juvenile salmon and bull trout migrating through the EW (see Section 8.1.1.8). Because the EW is a busy working industrial waterway and is also used by tribes for a commercial salmon netfishery, coordination is necessary with EPA, National Marine Fisheries Service, U.S. Fish and Wildlife Service, the tribes, Port tenants, and other waterway users to ensure that disruptions of their activities are minimized during remediation. This feasibility factor affects all the action alternatives similarly, generally proportional to the construction timeframe for the alternatives.

In addition, navigation channel reauthorization is an administrative challenge for some alternatives. Alternatives 1A(12), 1B(12), 1C+(12), 2B(12), 2C+(12), and 2C+(7.5) include partial dredging and capping in the Shallow Main Body – South CMA, which would require the federal navigation channel to be reauthorized to shallower depths in that area to accommodate capping.

For implementability, the alternatives are ranked relative to each other, with five stars representing the most implementable, and one star representing the least implementable. The ranking considers two primary metrics equally: 1) technical implementability, with the key differentiating factor being the approach to remediating the technically challenging sediments under the piers; and 2) administrative implementability, with the key differentiating factor being the overall complexity of the cleanup, which accounts for annual challenges of permitting, fisheries coordination, Port tenant and shipping vessel coordination, and staging.

As shown in Table 11-1, Alternative 3E(7.5) receives the lowest rank (★) for implementability relative to the other alternatives, largely due to technical challenges associated with 12 construction seasons of diver-assisted hydraulic dredging over large areas of underpier sediment, placement of in situ treatment material under the piers, and has the largest overall scope of the alternatives (13 years of construction). Alternatives 1C+(12), 2C+(12), 3C+(12), and 2C+(7.5) receive a relatively low ranking (★★) because they employ some diver-assisted hydraulic dredging followed by in situ treatment under the piers and have moderate overall scope of remediation (9 to 11 years). Alternatives 1B(12), 2B(12), and 3B(12) are considered moderately implementable (★★★) because they include in situ treatment performed in underpier areas (which is significantly more implementable than diver-assisted hydraulic dredging) and have moderate overall scope of remediation (9 to 11 years). Alternative 1A(12), while having similar construction aspects in open water to Alternatives 1B(12) and 3B(12), scores the highest among the action alternatives (★★★★) because of the high implementability of performing MNR under the piers and a moderately lower overall scope (9 years of construction). The No Action Alternative is given the highest implementability rank (★★★★★) because it has no construction elements and no provisions to trigger contingency actions.

11.1.7 Cost

Figure 11-3 depicts the costs for the remedial alternatives plotted with the remedial technology areas. The No Action Alterative is ranked five stars as the least expensive. The action alternatives are ranked relative to each other, with four stars representing the least expensive and one star representing the most expensive. The action alternatives are grouped based on ranges of costs using intervals of $30 million each (i.e., $240 to $270 million, $270 to $300 million, $300 to $330 million, and more than $330 million). As shown in Table 11-1, Alternative 3E(7.5) has the highest cost ($411 million), and therefore ranks lowest (★) for this criterion. Alternatives 3C+(12) and 2C+(7.5) are assigned low-moderate ranking (★★) with costs of $310 and $326 million, respectively. Alternatives 1C+(12), 2B(12), 2C+(12), and 3B(12) receive a moderate ranking (★★★), with costs ranging from approximately $277 to $298 million. Alternatives 1A(12) and 1B(12) receive a relatively high ranking, with costs of approximately $256 and $264 million (★★★★). The No Action Alternative has the lowest cost ($950,000) and, therefore, has the highest ranking (★★★★★) for this criterion.

11.1.8 Cost-effectiveness

A statutory requirement that must be addressed in the ROD and supported by the FS is that the remedial action must be cost-effective (40 CFR § 300.430(f)(1)(ii)(D)). Cost-effectiveness is the consideration of both the costs and the benefits (or "overall effectiveness") for the remediation alternatives. The cost-effectiveness determination should carefully consider the relative incremental benefits and costs between the alternatives. In accordance with the National Contingency Plan, the cost of the selected remedy must not be greater than less costly alternatives that provide an equivalent level of protection (EPA 1999). For the cost-effectiveness evaluation, benefits were assessed using long-term effectiveness and permanence and short-term effectiveness. Figure 11-4 depicts overall effectiveness metric (including long-term and short-term effectiveness metrics) and costs for the alternatives.

The least costly action alternative, Alternative 1A(12), does not rank as highly for overall effectiveness compared to the other action alternatives, primarily due to increased time to achieve RAOs and slightly higher risks compared to the other action alternatives. Moreover, the cost savings for this alternative are not commensurate with the decreased overall effectiveness for the alternative. While the most costly alternative, Alternative 3E(7.5), results in the largest removal volume, it does not provide a commensurate improvement in overall effectiveness relative to the other action alternatives (i.e., there is no appreciable reduction in site-wide risks). Further, the incremental cost of this alternative relative to the next most costly alternative ($85 million) is disproportionate to any additional environmental benefits achieved.

The rest of the action alternatives (Alternatives 2B(12) through 2C+(7.5)) have similar overall effectiveness, with the alternatives with only in situ treatment under the piers (Alternatives 1B(12), 2B(12), and 3B(12)) ranking higher for short-term effectiveness than the alternatives that include diver-assisted hydraulic dredging (Alternatives 1C+(12), 2C+(12), 3C+(12), and 2C+(7.5)). The benefits among these alternatives (particularly those related to human health risk reduction) do not increase with higher costs; therefore, lower-cost alternatives are preferred because they tend to be more cost-effective.

11.2 Risk Management Principles and National Guidance

The EW is one of many large and complex contaminated sediment sites in the country. Many sites in other regions are addressing similar issues and uncertainties. In response, EPA released the *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002a), which can be found in Appendix A of the *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005). This FS process developed and evaluated the alternatives for the EW in a manner consistent with these documents, most specifically with the 11 risk management principles set forth below:

1. **Control Sources Early:** Source control in the EW OU has been ongoing under applicable federal and state regulations (e.g., Clean Water Act). Source tracing and control efforts include ongoing source tracing sampling, operating and maintaining SD and CSO systems, complying with NPDES permits, implementing County and City CSO Control Plans, inspecting local businesses and implementing BMPs, and conducting upland cleanups. Empirical data and modeling efforts to date suggest that the effects of lateral loadings should be localized for current and future loading from lateral sources (e.g., SDs and CSOs). In addition, data and modeling have identified that broader regional inputs from upstream and from atmospheric sources will affect the long-term surface sediment concentrations in the EW.
2. **Involve the Community Early and Often:** Stakeholders were engaged as early as the development of the scope of work and through the duration of the project. The baseline risk assessments evaluated potential site uses by workers and local populations, including tribal members and Asian and Pacific Islanders. These risk results have been factored into developing the long-term cleanup goals for the EW. EPA will consider input from the affected community on the FS and when developing the Proposed Plan.
3. **Coordinate with States, Local Governments, Tribes, and Natural Resource Trustees:** The Muckleshoot and Suquamish Tribes, DNR, and NOAA have all been closely involved in the studies completed to date on the EW. EWG, which includes three local government agencies, will continue to share key concepts and issues related to the cleanup with NOAA, the tribes, and DNR.
4. **Develop and Refine a Conceptual Site Model that Considers Sediment Stability:** Empirical data and modeling have been used to develop a CSM of the EW, which is summarized in Section 2 and described in detail in the SRI (Windward and Anchor QEA 2014). The CSM indicates that the EW is a net depositional system, with areas subject to episodic scouring as a result of vessel activity within routine operating parameters, but not from estuarine flows. Potential vessel scour depths were considered in developing the remedial footprint, assigning remedial technologies, and predicting the performance of remedial alternatives.

5. **Use an Iterative Approach in a Risk-based Framework:** Studies by the NRC (2007) and other independent, scientific peer reviews of sediment sites throughout the country (USACE 2008a; Cannon 2006) conclude that substantial uncertainties exist related to cleanup of complex sites such as the EW and point to the necessity of using adaptive management strategies. The action alternatives all include monitoring and potential contingency actions as needed to achieve RAOs.
6. **Evaluate the Assumptions and Uncertainties Associated with Site Characterization Data and Site Models:** A complex study, completed over the past 8 years, has been conducted and includes extensive site characterization and models for evaluating sediment stability and long-term recovery in the EW. Key uncertainties have been considered in evaluating the alternatives, and the effects of these uncertainties have been discussed in the evaluation of alternatives.
7. **Select Site-specific, Project-specific, and Sediment-specific Risk Management Approaches that Will Achieve Risk-Based Goals:** This principle summarizes the approach used in this FS. EW OU-specific risk-based goals have been developed. A range of remedial alternatives have been developed that consider location-specific uses, physical constraints, and the limitations of the remedial technologies. Finally, those alternatives have been compared to risk-based goals and background levels to help develop risk management approaches that include a range of actions. The action alternatives include a combination of technologies to look at the most effective ways to manage risk, and also include monitoring and adaptive management to maintain reduction in risks in the long-term.
8. **Ensure that Sediment Cleanup Levels are Clearly Tied to Risk Management Goals:** The RAOs developed for the EW are based on the results of the baseline human health and ecological risk assessments (Windward 2012a, 2012b). The sediment PRGs associated with each RAO are based on the results of the risk assessments or ARARs. The alternatives share the same PRGs and ultimately have the same risk management goals. Long-term sediment and fish tissue concentrations will be measured as part of site-wide monitoring for the action alternatives to assess remedy effectiveness.
9. **Maximize the Effectiveness of Institutional Controls and Recognize Their Limitations:** To be fully protective, the selected remedy will require institutional controls. Seafood consumption advisories are expected to continue indefinitely under all of the alternatives because background levels are predicted to result in risks exceeding

thresholds. Seafood tissue contaminant concentrations are predicted to increase in the short term as a result of dredging. Many studies have shown seafood consumption advisories to be of limited efficacy. Recommended actions for public education, outreach, and notification control elements are the same for the action alternatives. The no action alternative does not include institutional controls for managing residual risks beyond the existing WDOH seafood consumption advisory. Monitoring and notification of waterway users is essential where contamination remains in place following remediation (particularly the containment-focused alternatives, in areas where capping has been utilized). Such controls have been successfully implemented at a wide range of sites regionally and nationally.

10. **Select Remedies that Minimize Short-term Risks while Achieving Long-term Protection:** the action alternatives include various combinations of remediation technologies. This allows each alternative's performance to be compared with respect to short-term risks and long-term protection. Although all the alternatives achieve similar long-term risk-reduction goals, the time to achieve these goals is different. Conversely, short-term risks to the community and workers and environmental impacts are closely tied to the construction period and remedial technologies used for each alternative. Short-term risks during construction include worker safety, transportation-related impacts on communities, air emissions, habitat disruption, and elevated contaminant concentrations in resident fish and shellfish tissue during and a few years following dredging.
11. **Monitor During and After Sediment Remediation to Assess and Document Remedy Effectiveness:** the action alternatives include extensive short-term and long-term monitoring programs to assess effectiveness, and the cost estimates assume contingency actions based on monitoring results. The No Action Alternative includes long-term site-wide monitoring but does not assume any contingency actions based on the latter monitoring.

11.3 Managing the Key Uncertainties

Decision-making on a site of the size and complexity of the EW requires careful consideration of uncertainties in the FS data and analyses. The uncertainties associated with the EW FS are similar to other large sediment remediation sites. Many of the uncertainties in this FS affect all alternatives to a similar degree and therefore do not significantly affect the relative comparison of alternatives. A sensitivity analysis was performed for the FS to understand the impacts of key parameters on the performance of the alternatives. For Alternatives 2B(12) through 3E(7.5) (all of the action alternatives with the exception of Alternative 1A(12)), the range of predicted SWACs between the alternatives was smaller than the range of predicted SWACs between sensitivity runs for a single alternative, with no change in risk outcome for any sensitivity run (Figure 11-5). The following factors emerge as particularly important for managing uncertainty relative to the anticipated performance of the alternatives:

- Predictions of average surface sediment contaminant concentrations are greatly influenced by a number of factors related to incoming sediment concentrations, vessel scour, sediment remaining adjacent to structures, and dredge residuals. Sediment mixing can increase or decrease sediment concentrations in the EW, depending on the concentrations that are being mixed. Dredge residuals thickness, concentration, and distribution will vary as a result of quality and thickness of sediment being dredged, hydrodynamic and operational conditions during construction, and BMPs employed. The presence of dredge residuals will be mitigated to the extent practicable by using BMPs and implementing an adaptive management framework to monitor and perform contingency actions as necessary to minimize the impact of residuals.
- As a result of the large amounts of relatively clean sediments from Green River upstream that deposit within the EW, surface sediment contaminant concentrations are predicted to converge to levels similar to the quality of incoming sediment from the Green River (general urban inputs from EW laterals and the LDW laterals and resuspended bedded sediment are expected to have very little impact on predicted SWAC values, based on the total mass of loads to the EW from these two sources (0.7%) compared to other upstream sources (i.e., Green River sediments), resulting in similar levels of risk over time among the action alternatives. The concentrations of these inputs are uncertain and will change over time in response to many factors, including upstream cleanups, upstream source control, and source control in the EW drainage basin.
- Technical challenges associated with the technologies for remediating underpier areas are a key uncertainty in this FS.
  - The performance of MNR in underpier areas is less certain compared to the other remedial technologies; however, MNR poses very few technical challenges.

  - The performance of in situ treatment depends on many site-specific complex physical and chemical factors, and constructability of the in situ treatment technology includes important technical challenges for placing material on steep slopes in difficult-to-access areas (due to the presence of the supporting piles and the low overhead clearance under the pier deck surfaces). Another potential uncertainty relates to sediment stability and the location and amount of exchange of material with open-water areas with regard to potential for recontamination of adjacent areas. However, underpier areas have relatively small spatial extent and, therefore, are expected to contribute less to site-wide risks from bioaccumulative compounds, as shown in model predictions (see Section 9.15.1.2).
  - Finally, diver-assisted hydraulic dredging is associated with large uncertainty with both performance and technical implementability. Performance is uncertain with respect to the quantity of contaminated sediment that will be left behind due to conditions under piers (e.g., riprap interstices and debris). However, diver-assisted hydraulic dredging has less uncertainty related to exchange of sediment with open-water areas, compared to in situ treatment alone, because there is less sediment available for exchange. Technical implementability is also uncertain with respect to the construction timeframe and costs associated with removing underpier sediments in deep water with low visibility from presence of suspended sediments and variable conditions under piers (e.g., presence of debris, cables, large wood, and broken pilings). Underpier work has the potential for prolonged impacts and delays from vessel operations. Extensive dewatering and water management operations are associated with hydraulic dredging. Substantial health and safety risks are posed by this type of underwater construction and management of those risks can slow the implementation or limit the areas that can be safely dredged by divers.

- The performance of the remedial technologies outside of underpier areas also have uncertainties, which are mitigated by adaptive management.

  - Dredging results in the release of contaminants to the water column (which can maintain elevated fish and shellfish tissue contaminant concentrations over the short term) and dredge residuals to the sediment surface. As described in Appendix A, full removal of all contaminated sediment is not possible in many areas near structures, where setbacks and stable slopes required for structure protection will leave some contaminated sediments behind. Long-term site-wide predictions will depend on the location and amount of sediment remaining adjacent to structures, and the potential for it to be disturbed from propwash.

- Capping, ENR, and in situ treatment require ongoing monitoring and may need periodic maintenance. MNR performance may be slower or faster than predicted and may require additional monitoring or potential contingency actions. These uncertainties would be managed in the long term under the action alternatives by the required monitoring, contingency actions, and repairs as needed. Cost estimates in this FS include the costs of these long-term management activities. These activities would be enforceable requirements under a Consent Decree (or similar mechanism), and EPA is required to review the effectiveness of their selected remedy no less frequently than every 5 years.

- Uncertainty exists in the predictions of resident seafood tissue contaminant concentrations and associated human health risks for total PCBs and dioxins/furans following remediation. This uncertainty is driven by: 1) exposure assumptions from the human health risk assessment; 2) assumptions used in the food web model for total PCBs such as uptake factors and future water concentrations; and 3) uncertainties in biota-sediment accumulation factors used for dioxins/furans (see Section 8.3.2 of the EW SRI, Windward and Anchor QEA 2014) The predictions of resident seafood tissue contaminant concentrations and risks are nevertheless useful for comparing the alternatives to one another because the uncertainties are the same for all alternatives, and therefore all of the alternatives should be affected similarly.

These types of uncertainties were addressed by bounding and uncertainty analyses to understand their potential effects. Overall, predicted average surface sediment concentrations after remediation are more affected by uncertainty factors (e.g., chemistry of Green/Duwamish River sediments and net sedimentation rates) than by expected differences associated with the remedial alternatives themselves. However, this analysis is performed using a common set of assumptions for all alternatives to demonstrate the potential differences among alternatives. Most effects are consistent across alternatives, and therefore, the relative comparison of alternatives is still appropriate to assess cleanup alternatives.

11.4 Next Steps

EPA and EWG will solicit input from the public, including stakeholders, such as tribes and other trustees, to be incorporated into the final FS. EPA will issue a Proposed Plan that identifies a preferred remedial alternative for the EW. Formal public comment will be sought on the Proposed Plan. After public, state, and tribal comments on the Proposed Plan are received and evaluated, EPA will select the final remedy and issue the ROD. The cleanup standards, objectives, and RALs will be specified in the ROD, which is anticipated to be issued with state concurrence. The ROD may also specify final post-construction goals for some or all remediated areas. After the ROD is issued, the first 5-year period is expected to include conducting source control activities as needed; negotiating one or more consent decrees for performance of remedial design and cleanup; conducting predesign investigations, baseline monitoring, and remedial designs; and developing a compliance monitoring program for active cleanup areas. The long-term monitoring plan will be designed to assess achievement of RAOs, evaluate performance of the cleanup, and trigger contingency actions and adaptive management steps as needed.

11.4.1 Ongoing Source Control Efforts

The EW source control approach focuses on controlling contamination that affects EW sediments. It is based on the principles of source control for sediment sites described in *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002a) and similar Washington State requirements. EWG coordinates and implements source control efforts in the EW and works in cooperation with local jurisdictions, Ecology, and EPA to implement source control actions.

It is important to note that in localized areas, some recontamination may occur even with aggressive source control because of the difficulty in identifying and completely controlling all potential sources of certain ubiquitous contaminants that are widely released by urban activities (e.g., phthalates). Other contaminants with the possibility of exceeding action levels near outfalls based on the FS analysis include 1,4-dichlorobenzene, dioxins/furans, and mercury. For the EW, recontamination of EW sediments will be controlled to the extent practicable under existing source control efforts and authorities. The goal is to limit sediment recontamination that exceeds location-specific standards, where feasible.

EPA's (2002a) sediment guidance recommends "control sources early, before sediment cleanup begins," but that may not always be practical. Delaying sediment cleanup until all sources have been identified and controlled, regardless of their contribution in terms of contaminant loading, may delay achieving many of the benefits that sediment cleanup alone can accomplish. The EW source control efforts have been performed in parallel with the SRI and FS and will continue before, during, and after the implementation of the remedy. Source tracing and control efforts include:

- Conducting ongoing source tracing sampling
- Operating and maintaining storm drain and CSO systems
- Complying with NPDES permits
- Implementing County and City CSO Control Plans
- Inspecting local businesses that discharge or otherwise contribute to storm drains and CSOs to ensure that they are implementing appropriate BMPs to reduce the amount of pollution discharged from their property
- Conducting upland cleanups and monitoring to protect sediments from contaminated soils and groundwater

Because of the dynamic nature of many source control activities and the understanding of recontamination potential over time, it is essential to maintain flexibility when adapting source control efforts to specific needs within source control areas. The success of source control depends on cooperation of all relevant parties and the active participation of businesses that must make changes to accomplish source control goals. This adaptive strategy for prioritizing source control work will continue throughout selection, design, and implementation of the long-term remedy for the EW.

11.4.2 Adaptive Management for In-Water Sediment Remediation

Remediation of contaminated sediments in the EW under CERCLA should be undertaken in a flexible, iterative, and adaptive manner. Actions should be adjusted based on what has been learned from other cleanups and previous construction activities. The cleanup process of the EW should do the following:

1. Continue source control efforts, sequenced to the sediment remediation.
2. Address uncertainties and provide flexibility in the design elements as more data become available. Use the results of previous actions, including actions at adjacent sites to inform further sediment cleanup.
3. Monitor performance and changing conditions in both the remediation and source control efforts.
4. Implement contingency actions that may become needed over time.

Experience at other complex sediment sites points to the necessity of using adaptive management strategies, as recommended by EPA guidance (EPA 2005), the NRC (2007), and other independent, scientific peer reviews of sediment sites throughout the country (USACE 2008a; Cannon 2006). For adaptive management to work effectively, it must be informed by data. Further actions can be adjusted based on what has been learned from previous construction seasons. A long-term monitoring plan will be established with metrics and analyses that meet clearly articulated data quality objectives. Baseline monitoring will be conducted prior to beginning the initial remedial activities to establish a benchmark for evaluating the effectiveness of the remediation. Collecting monitoring information during and after cleanup will help evaluate the effectiveness of the selected remedial alternative, and trigger the planning and execution of contingency actions as needed. Because remediation and source control efforts will take years to occur, and biological response may take even longer, monitoring the changes in contaminant inputs and responses of various media in the EW will be important to help determine when and to what extent contingency actions may be needed. Contingency actions may include more sediment remediation or source control efforts.

In the EW, adaptive management could be used to maximize the rate at which site-wide risks are reduced, while minimizing the uncertainties associated with remediation. In particular, remediation of underpier sediments, which represent a relatively small area (12 acres), have more uncertainty associated with performance and/or implementability for all retained remedial technologies (MNR, in situ treatment, and diver-assisted hydraulic dredging). In particular, diver-assisted hydraulic dredging is more hazardous for worker health and safety and likely to have high costs and short-term impacts that are disproportionate to the long-term benefits (i.e., reduction in risk) due to the significant amount of contaminated sediment that will remain following diver-assisted dredging (see Section 7.2.6.3). For these reasons, adaptive management principles will be particularly important for remediating underpier sediments in effective and practicable ways.

EPA will evaluate the effectiveness of the selected remedial alternative every 5 years subsequent to completion of remediation. The 5-year reviews will integrate comprehensive evaluations of the seafood consumption advisories, outreach and education programs, source control work, remedy effectiveness, and changes in overall waterway health. These periodic reviews can be used by EPA in conjunction with the performance monitoring program to identify the need for any additional course corrections (e.g., contingency actions, review endpoints, modify technologies, or conduct more monitoring) in the cleanup.

	Achieve Threshold Criteria?	Long-term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-term Effectiveness	Implementability	Cost
No Action	No	Low	Low	Low	Very high	Very high
1A(12)	Yes	Moderate	Low	Low-moderate	Relatively high	Relatively high
1B(12)	Yes	Relatively high	Very high	Very high	Moderate	Relatively high
1C+(12)	Yes	Relatively high	Very high	Relatively high	Low-moderate	Moderate
2B(12)	Yes	Very high	Very high	Relatively high	Moderate	Moderate
2C+(12)	Yes	Very high	Very high	Moderate	Low-moderate	Moderate
3B(12)	Yes	Very high	Very high	Relatively high	Moderate	Moderate
3C+(12)	Yes	Very high	Very high	Moderate	Low-moderate	Low-moderate
2C+(7.5)	Yes	Very high	Very high	Low-moderate	Low-moderate	Low-moderate
3E(7.5)	Yes	Very high	Very high	Low	Low	Low

- Ranks very high compared to other alternatives
- Ranks relatively high compared to other alternatives
- Ranks moderate compared to other alternatives
- Ranks low-moderate compared to other alternatives
- Ranks low compared to other alternatives

Notes:

Low costs are given a high rank, and high costs are given a low rank.

CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act

Figure 11-1
CERCLA Comparative Analysis of Alternatives
Feasibility Study
East Waterway Study Area

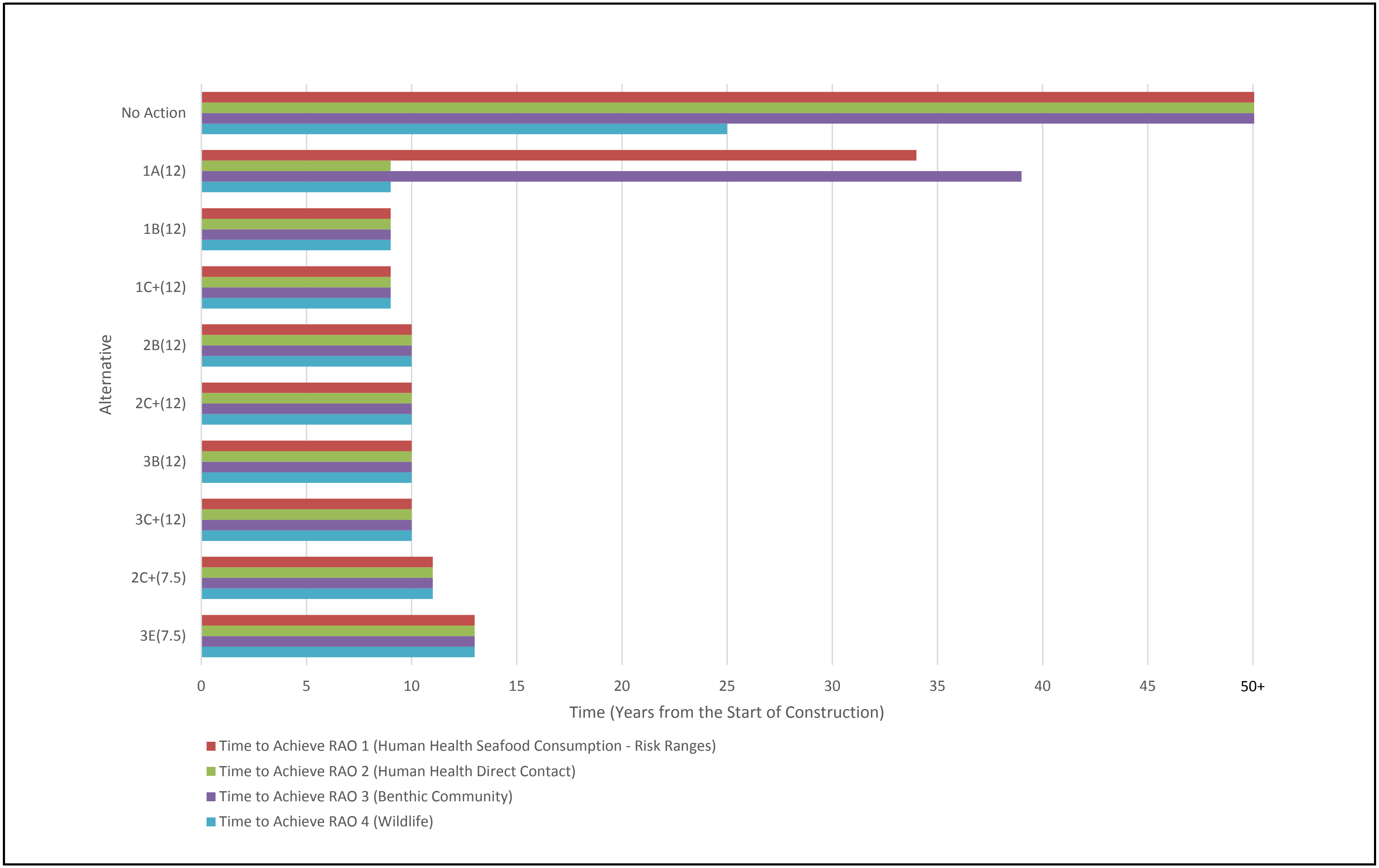
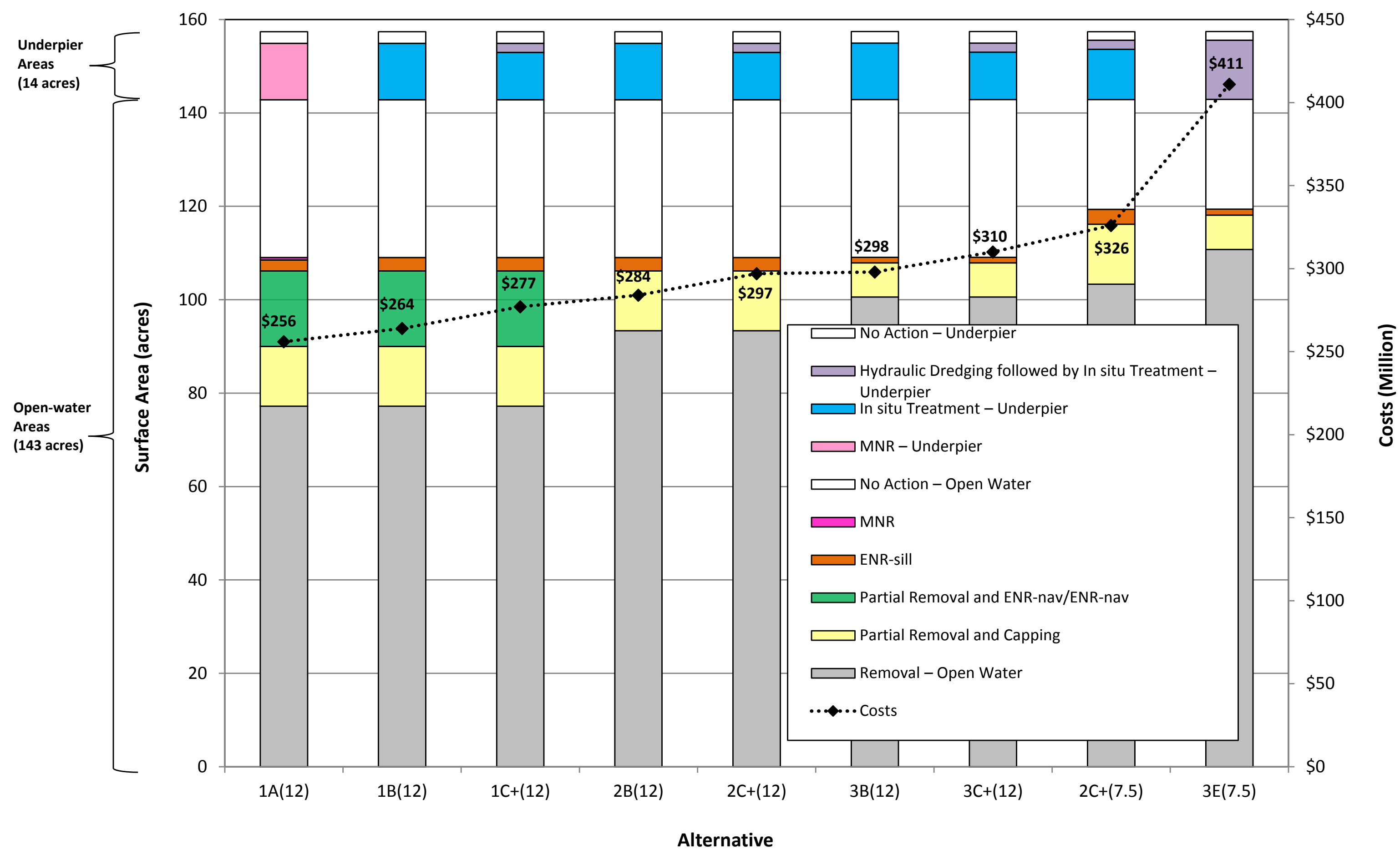


Figure 11-2
Time to Achieve Remedial Action Objectives
Feasibility Study
East Waterway Study Area



Notes:

1. The total East Waterway Operable Unit surface area is 157 acres.
2. Removal - Underpier is diver-assisted hydraulic dredging.
3. ENR-sill is enhanced natural recovery applied in the Sill Reach.
4. ENR-nav is enhanced natural recovery applied in the navigation channel and deep-draft berthing areas.

ENR = enhanced natural recovery; MNR = monitored natural recovery

Figure 11-3
Costs and Remediation Areas for the Action Alternatives
Feasibility Study
East Waterway Study Area

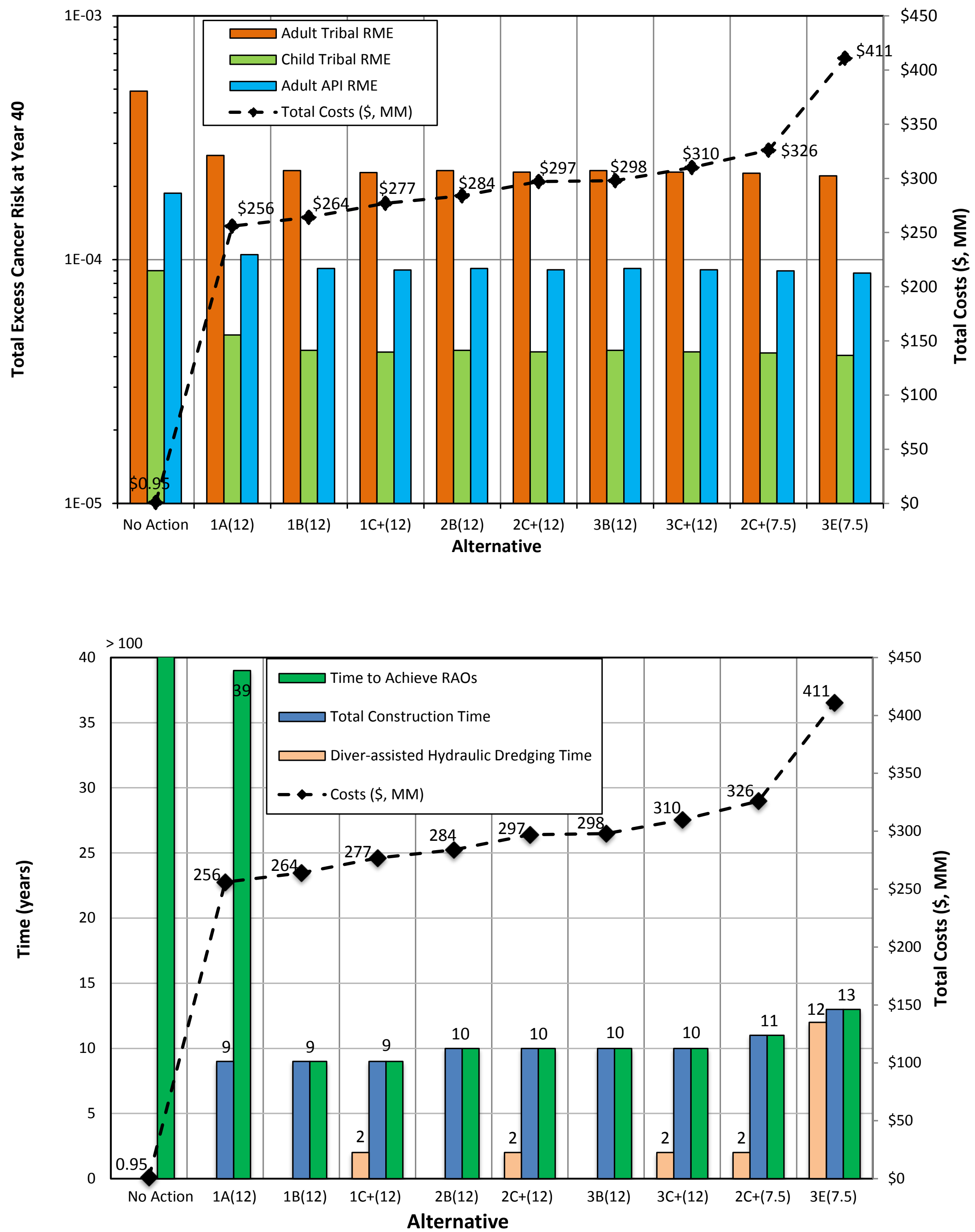
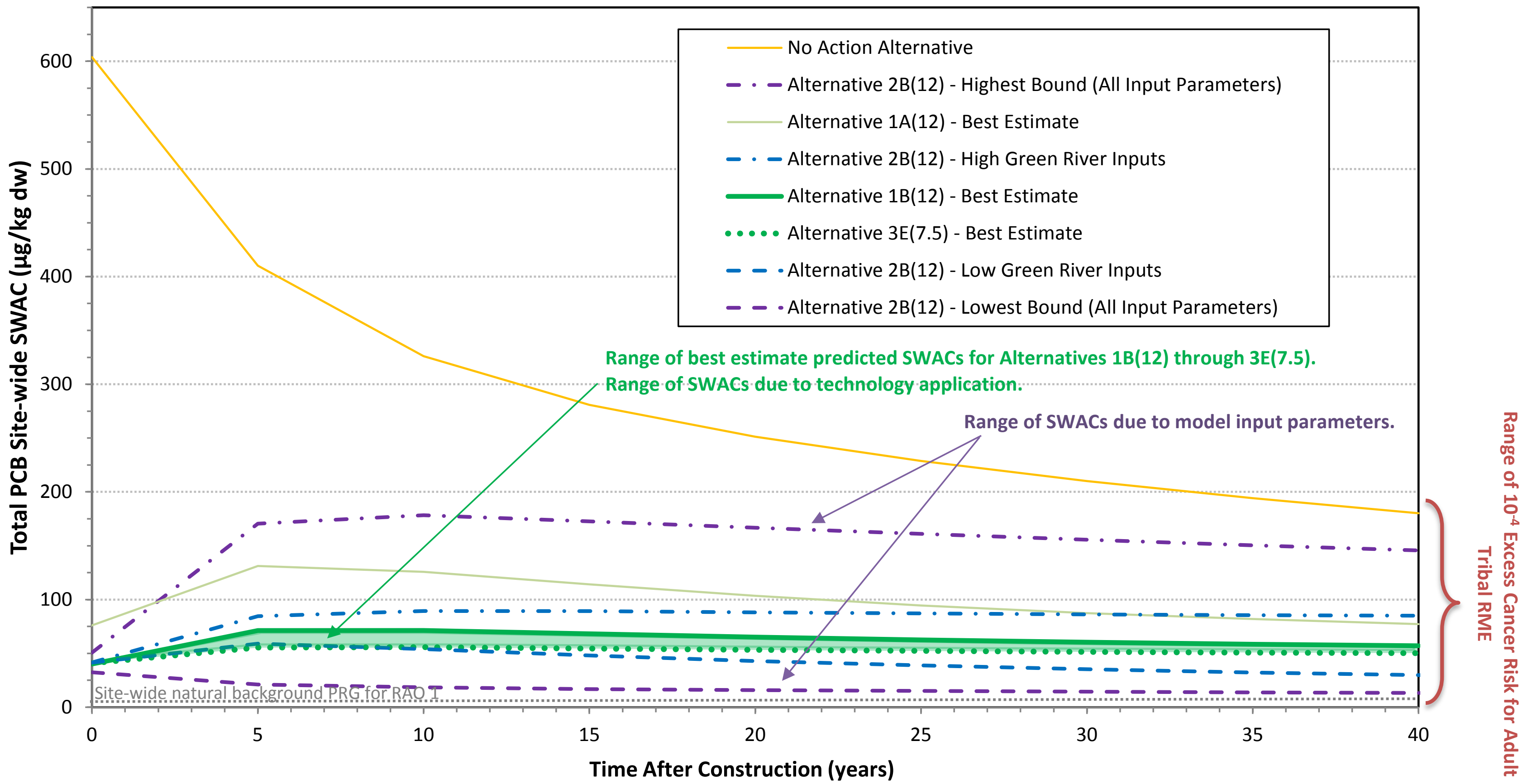


Figure 11-4
Overall Effectiveness and Costs for Alternatives
Feasibility Study
East Waterway Study Area



Notes:

µg/kg = microgram per kilogram; dw = dry weight; PRG = preliminary remediation goal; RAO = remedial action objective; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration

Figure 11-5

Predicted Site-wide Total PCB SWACs Over Time for Action Alternatives

Feasibility Study

East Waterway Study Area

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APPENDIX A – SUPPLEMENTAL INFORMATION FOR SELECTION OF PRGS
EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

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APPENDIX A TABLE OF CONTENTS

PART 1: COMPLIANCE WITH SEDIMENT MANAGEMENT STANDARDS

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1 INTRODUCTION

The Feasibility Study (FS) for the East Waterway (EW) Operable Unit (OU) has been developed under the regulatory framework of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Consistent with CERCLA requirements, the selected alternative must substantively comply with applicable or relevant and appropriate requirements (ARARs), which include portions of the Washington State Sediment Management Standards (SMS). The SMS are the Washington State standards for remediating sediments under the Model Toxics Control Act (MTCA). This appendix provides a brief description of the methods and procedures for establishing cleanup levels under the SMS, and also discusses how the EW alternatives developed under CERCLA can comply with SMS requirements.

This appendix is provided solely for the purpose of evaluation of the remedial action alternatives in the FS and presents a projection of how these alternatives may achieve compliance with those portions of the SMS that are anticipated to be ARARs based on assumptions about future conditions after remediation. Once the United States Environmental Protection Agency (EPA) selects ARARs for the EW OU as part of a Record of Decision (ROD), the mechanism of compliance with the selected portions of the SMS will be determined by EPA during or at the completion of the remedial action.

The preliminary remediation goals (PRGs) presented in Section 4 of the FS were developed to comply with portions of the SMS that are ARARs under CERCLA, including the determination of cleanup levels[1] under Washington Administrative Code (WAC) 173-204-560. The SMS cleanup level determination is performed by determining the sediment cleanup objectives (SCO; discussed in Section 2 of this appendix) and the cleanup screening levels (CSL; discussed in Section 3 of this appendix). The cleanup levels are initially set at the SCO. If the SCO is not technically possible to attain, or would result in net adverse environmental impacts, then the cleanup level can be adjusted up to the CSL.

[1] For the purposes of this appendix only, the SMS term "cleanup level" is considered analogous to the CERCLA term "PRG" used in the main text of the FS. This appendix sometimes uses the term "cleanup level" for consistency with the SMS. In other contexts, these terms may not have the same meaning.

For several contaminants of concern (COCs) in the FS, SCO-based PRGs have been established at their natural background concentration because risk-based SCO concentrations are lower than the natural background concentration. This is consistent with SMS. Although both SMS and CERCLA allow for a regional background-based value to be considered as well,[2] there is no EPA-approved regional background concentration determined for the EW area. In the absence of regional background values, cleanup levels (i.e., PRGs) for these COCs are based on the SCO in the EW FS. For some of these COCs, the modeling and associated analyses presented in this appendix indicated that the SCO is not technically possible to achieve. Empirical long-term monitoring data will allow for a more informed evaluation of technical possibility.

For the purpose of informing alternatives in the FS (Section 4.1.1), EPA requested that additional modeling of a "hypothetical maximum remediation scenario" be conducted to estimate the lowest concentration that could be achieved as a result of remedy implementation. This modeling was conducted to estimate post-construction concentrations and was not conducted for purposes of predicting the long-term outcome of any of the alternatives. The hypothetical maximum remediation scenario is based on a series of estimates using the best available data; however, these estimates are inherently uncertain. The modeling was based on FS-level evaluations and contains uncertainty insofar as detailed engineering design has not been conducted to inform the input parameters that affect the post-construction concentrations. While sensitivity and bounding analysis was completed for the long-term model predictions used in comparing FS alternatives, it was not conducted for the hypothetical maximum remediation scenario analysis. Nonetheless, the analysis provides information that could be used to evaluate whether it is technically possible to achieve natural background-based PRGs, and it provides additional information that EPA could consider for a potential future adjustment of cleanup levels under SMS or for a technical impracticability (TI) waiver under Section 121(d)(4)(C) of CERCLA, 42 U.S.C § 9621(d)(4)(C).

[2] The SMS term "regional background" is similar to the term "anthropogenic background" in EPA guidance (EPA 2002).

As described in Section 9 of the FS, model predictions indicate that long-term post-cleanup concentrations of total polychlorinated biphenyls (PCBs) and dioxins/furans will be higher than the natural background-based PRGs.[3] The modeling includes some assumptions for future source control for the EW and Lower Duwamish Waterway (LDW), but not for the upper Duwamish and Green Rivers, all of which contributes to uncertainty of predictions. While the analysis indicates that it will not likely be technically possible to achieve all natural background-based PRGs in the EW, the cleanup will still achieve the MTCA/SMS ARARs. This appendix discusses different mechanisms for SMS compliance.

Based on preliminary evaluations, the EW OU cleanup is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (remedial action objective [RAO] 2), protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. Modeling of the hypothetical maximum remediation scenario at the completion of cleanup implementation and modeling of long-term site-wide concentrations following source control of LDW and EW lateral inputs both predict that surface sediments in the EW OU will not attain all natural background-based PRGs for protection of human health for seafood consumption (RAO 1). Long-term site-wide concentrations are driven primarily by the ongoing contribution of elevated concentrations from diffuse, nonpoint sources of contamination that contribute to regional background concentrations. However, achieving the MTCA/SMS ARARs may nonetheless occur in one of two ways:

- Post-remedy monitoring may demonstrate sediment concentrations lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for a Sediment Recovery Zone (SRZ), as provided by the SMS at WAC 173-204-590(3) (see Section 5 of this appendix).

[3] Note that none of the alternatives is predicted to achieve the SCO for these chemicals; therefore, this appendix applies equally to any of the alternatives, if selected.

- Sediment cleanup levels (SCLs) may be adjusted upward if regional background levels are established for the geographic area of the EW (see Section 4 of this appendix). Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or Explanation of Significant Differences (ESD) (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition to these two potential MTCA/SMS ARARs compliance mechanisms, a final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4)(C) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

Because it is not known whether, or to what extent, the SMS ARARs for total PCBs and dioxin/furans will be achieved in the long term, the selection of which of the two compliance mechanisms described above (either meeting the natural background PRG in a reasonable restoration timeframe, or upwardly adjusting the SCL to regional background and meeting it in a reasonable restoration timeframe), is not identified at this time.

The rest of this appendix provides additional detail regarding establishing SCO (Section 2) and CSL (Section 3) concentrations, potentially upwardly adjusting cleanup levels in the future (Section 4), and implementation of an SRZ (Section 5). Section 6 provides a summary of the methods that may be used to comply with the SMS ARAR.

2 SEDIMENT CLEANUP OBJECTIVES

The SMS outline procedures for establishing the lower bound for cleanup levels, called the SCO. Multiple exposure pathways, natural background concentrations, and practical quantitation limits (PQLs) are all considered when determining the SCO, as follows:

> *WAC 173-204-560 (3) Sediment cleanup objectives. The sediment cleanup objective for a contaminant shall be established as the highest of the following levels:*
>
> *(a) The lowest of the following risk-based levels:*
>
> *(i) The concentration of the contaminant based on protection of human health as specified in WAC 173-204-561(2);*
>
> *(ii) The concentration or level of biological effects of the contaminant based on benthic toxicity as specified in WAC 173-204-562 or 173-204-563, as applicable;*
>
> *(iii) The concentration or level of biological effects of the contaminant estimated to result in no adverse effects to higher trophic level species as specified in WAC 173-204-564; and*
>
> *(iv) Requirements in other applicable laws;*
>
> *(b) Natural background; and*
>
> *(c) Practical quantitation limit.*

As summarized in Tables 4-3 and 4-4 of the FS, RAOs were established under CERCLA for the FS to be consistent with WAC regulations:

- Risk-based threshold concentrations (RBTCs) associated with RAOs 1 and 2 were established to be consistent with WAC 173-204-560(3)(a)(i)
- RBTCs associated with RAO 3 were established to be consistent with WAC 173-204-560(3)(a)(ii)
- RBTCs associated with RAO 4 were established to be consistent with WAC 173-204-560(3)(a)(iii)
- Natural background concentrations were established to be consistent with WAC 173-204-505(11)
- PQLs were established to be consistent with WAC 173-204-505(14)

The Washington State Department of Ecology (Ecology) Sediment Cleanup User's Manual (SCUM) II (Ecology 2017) is not an ARAR under CERCLA, although portions of SCUM II may be evaluated as "to be considered" (TBC) criteria. As discussed in Section 4 of the main body of the FS, EPA has prescribed other methods for determining natural background concentrations for establishing PRGs in compliance with CERCLA (e.g., see FS Table 4-2). Solely for informational and comparison purposes, it is noted that in SCUM II, the SCO based on natural background for total PCBs is listed at 3.5 micrograms per kilogram (μg/kg) dry weight (dw) and the SCO based on the PQL for dioxins/furans is listed at 5 nanograms (ng) toxic equivalent (TEQ)/kg dw, because these are the highest of the three SCO levels for these compounds. The arsenic SCO is also established at natural background, but SCUM II defines the natural background concentration for arsenic to be 11 milligrams per kilogram (mg/kg), which would be achievable based on best-estimate FS model results. However, EPA does not consider these values to be ARARs.

3 CLEANUP SCREENING LEVELS

The SMS outline similar procedures for establishing the upper bound for cleanup levels, called the CSL:

> *WAC 173-204-560 (4) Cleanup screening levels. The cleanup screening level for a contaminant shall be established as the highest of the following levels:*
>
> *(a) The lowest of the following risk-based levels:*
>
> *(i) The concentration of the contaminant based on protection of human health as specified in WAC 173-204-561(3);*
>
> *(ii) The concentration or level of biological effects of the contaminant based on benthic toxicity as specified in WAC 173-204-562 or 173-204-563, as applicable;*
>
> *(iii) The concentration or level of biological effects of the contaminant estimated to result in no adverse effects to higher trophic level species as specified in WAC 173-204-564; and*
>
> *(iv) Requirements in other applicable laws;*
>
> *(b) Regional background as defined in subsection (5) of this section; and*
>
> *(c) Practical quantitation limit.*

RBTCs associated with the CSL (excess cancer risk of 10^{-5} or hazard quotient of 1) are presented in FS Table 3-13 and are well below the SCOs for total PCBs and dioxins/furans. The SMS define regional background as follows:

> *WAC 173-204-505(16)*
>
> *Regional background means the concentration of a contaminant within a department-defined geographic area that is primarily attributable to diffuse nonpoint sources, such as atmospheric deposition or storm water, not attributable to a specific source or release. See WAC 173-204-560(5) for the procedures and requirements for establishing regional background.*

The CSL for total PCBs and dioxins/furans may be based on regional background concentrations, once established. However, in the absence of regional background concentrations deemed by EPA to be suitable for use at the EW OU, and because the risk-based levels are below the CSL, the CSL has not been established for total PCBs or dioxin/furans.

In the future, Ecology may establish regional background for the LDW, but Ecology has not yet suggested how this may be applied to the EW. EPA may consider this approach and information once provided by Ecology.

4 ADJUSTMENT OF CLEANUP LEVELS

As discussed previously, because regional background concentrations have not been determined for the EW and the upper bound for the cleanup level (the CSL) has not been determined, the cleanup levels in the FS are set at the SCO for total PCBs and dioxins/furans. However, if regional background concentrations suitable for use at the EW OU are established, then, following the SMS, the cleanup levels may be adjusted upward by EPA based on the following site-specific factors:

> *WAC 173-204-560(2)(a)*
> *(ii) Upward adjustments. The sediment cleanup level may be adjusted upward from the sediment cleanup objective based on the following site-specific factors:*
>> *(A) Whether it is technically possible to achieve the sediment cleanup level at the applicable point of compliance within the site or sediment cleanup unit; and*
>> *(B) Whether meeting the sediment cleanup level will have a net adverse environmental impact on the aquatic environment, taking into account the short- and long-term positive effects on natural resources, habitat restoration, and habitat enhancement and the short- and long-term adverse impacts on natural resources and habitat caused by cleanup actions*

The following sections discuss the site-specific factors that could be considered by EPA to adjust the cleanup levels from the SCO.

4.1 Technical Possibility

The SMS defines "technical possibility" as follows:

> *WAC 173-204-505(23)*
> *"Technically possible" means capable of being designed, constructed and implemented in a reliable and effective manner, regardless of cost.*

Considerations for upward adjustments of cleanup levels based on technical possibility are provided in Ecology's SCUM II guidance document, which states that upward adjustments of cleanup levels under WAC 173-204-560(2)(a)(ii)(A) should be based on "whether it is technically possible to achieve *and maintain* the cleanup level at the applicable point of compliance." [emphasis added] Although SCUM II is not an ARAR, this provision of Ecology's guidance is similar to EPA's environmental criterion requiring long-term maintenance of remedial action alternatives.

This section first estimates the lowest technically possible concentrations that could be achieved in the EW immediately following construction for a hypothetical maximum remediation scenario (Section 4.1.1). The post-construction concentration modeling for the hypothetical maximum remediation scenario was based on FS-level evaluations using best available data, but contains uncertainty, as detailed engineering design has not been conducted to inform the input parameters that affect the post-construction concentrations, and no sensitivity or bounding analysis was completed. Additional design evaluations will be conducted in the future following the ROD.

This appendix also evaluates what is technically possible to maintain in the long term following construction (Section 4.1.2). Uncertainty also exists regarding long-term concentrations, including future conditions following source control, as described in FS Appendix J.

The combination of the hypothetical maximum remediation scenario evaluations and the evaluation of what is technically possible to maintain in the long term following construction may be used by EPA to evaluate technical possibility. This analysis is developed for FS purposes only.

4.1.1 Technical Possibility of Hypothetical Maximum Remediation Scenario

The EW is a highly urbanized, commercial waterway with actively used marine transportation infrastructure along most of the shoreline area that limits the remedial activities that can occur. For example, full removal of all contaminated sediment near structures is not possible without affecting structural stability. As a result, some amount of undisturbed contaminated sediment will in all likelihood remain near structures following remediation; however, measures to practicably reduce remaining contaminated sediment will be considered in the design phase.

This section describes an FS-level analysis on a hypothetical site-wide dredging scenario to estimate the lowest concentration that may be technically possible to achieve for total PCBs at the completion of construction. The scenario was developed assuming that all engineered infrastructure such as piers, engineered embankments, keyways, bridges, and the communication cable crossing would remain in place. Removing and reconstructing the infrastructure associated with the EW would require massive modifications (e.g., reconstructing the West Seattle Bridge, temporarily closing important Coast Guard and Port of Seattle terminals, etc.) that would result in excessive disturbance to essential public and private infrastructure. Moreover, this scenario assumed that remediation would be performed by dredging everywhere possible and included residuals management re-dredging passes where practicable to further lower concentrations. Dredging was assumed to be followed by residuals management cover (RMC) in most locations and was assumed to be followed by in situ treatment with activated carbon in under pier and keyway areas where RMC material could not be placed due to stability concerns and navigation depth requirements.

Note that this hypothetical scenario was created for the purposes of developing alternatives in support of the FS and does not itself represent an alternative in the FS; nor is it intended to provide definitive predictions regarding future concentrations in the EW. Also note that this analysis estimates concentrations at a single point in time (immediately after construction)—ignoring ongoing mixing, propwash, and incoming sedimentation during the construction period (Section 4.1.2). The scenario is based on estimates using best available data, but is subject to uncertainty, as detailed design evaluations have not been conducted.

To support this analysis, the EW was divided into six areas based on the physical constraints of each (Table 1, Figure 1). Spatially-weighted average concentrations (SWACs) immediately following construction were calculated using the box model inputs for each as summarized in the following paragraphs.

Area 1

The first area consists of most of the open-water areas of the waterway (114 acres) and has the fewest structural limitations affecting remediation. In these areas, the assumed remediation scenario was dredging the waterway to the deepest extent of contaminated sediment, followed by two residuals management re-dredging passes (average of 2 feet removal for each), followed by RMC placement. The resulting concentration immediately following construction in surface sediment (top 10 centimeters [cm]) was estimated to be 10 µg/kg dw for total PCBs for this area, based on the dredging residuals calculation methodology presented in FS Appendix B, Part 3A.

Area 2

The second area includes 15 acres of under pier sediments that have limited access and are present on top of slopes comprised of large riprap (see Figure 2). Remediation in these areas is challenging due to access limitations and the presence of hard riprap surfaces and rock interstices. These areas were assumed to be dredged by diver-assisted hydraulic dredging, followed by a thin placement of in situ treatment material to reduce bioavailability of the remaining sediment. The resulting post-construction concentration was estimated to be 290 µg/kg dw for total PCBs. This assumed that an average of 10 cm (3.9 inches) of sediments would remain in place following remediation due to the difficulty of full removal on riprap slopes and within rock interstices, followed by the mixing of 7.6 cm (3 inches) of in situ treatment material (see residuals calculations presented in FS Appendix B, Part 3A). In situ treatment material was also assumed to reduce the bioavailability of hydrophobic organic compounds such as PCBs by 70% (FS Section 5.3.5), resulting in an estimated effective bioavailable under pier average concentration estimated on a dry-weight basis of 153 µg/kg[4]. Note that in situ treatment is a less proven technology than the others presented in this evaluation and, therefore, in situ treatment is used only in areas where other, more-proven technologies are not feasible or unlikely to be effective, such as under the piers (see Section 7.2.7.1 and 7.8 of the FS). Reduction in bioavailability is approximated from available evidence from bench-scale studies and field demonstrations (FS Section 5.3.5) and is subject to uncertainty (Section 2.4 of FS Appendix J).

[4] Note the dry-weight concentration is intended to estimate bioavailability reduction to support calculation of a site-wide SWAC that considers the benefits of the application of in situ treatment material, but this concentration is not what would be measured on a dry-weight basis following construction.

Area 3

The third area includes 7 acres of keyways that are at the base of the under pier slopes (see Figures 1 and 2). These are rock structures keyed into the toe of the riprap slopes to maintain the stability of the slopes above. The tops of the keyways are situated at the navigation depth of approximately -51 feet mean lower low water, therefore limiting the amount of removal and the amount of clean fill placement that can be performed in these areas. Similar to the under pier areas, these areas were assumed to be dredged to the maximum extent possible without removing riprap, followed by a thin placement of in situ treatment material to reduce bioavailability. For this analysis, dredging was assumed to be performed by standard mechanical means. The resulting post-construction concentration was estimated to be 364 µg/kg dw for total PCBs based on an average of 10 cm (3.9 inches) of sediment remaining following dredging, with a 7.6-cm (3-inch) layer of clean in situ treatment material being placed following dredging. The effective bioavailable average concentration in keyways (using a 70% reduction in dry weight concentrations) was estimated to be 192 µg/kg. Note that the placement of in situ treatment material in keyways presented for this evaluation is hypothetical to support this evaluation; however, some keyway areas are already at the required navigation elevation and placement would not be possible in some areas due to navigation requirements. In addition, long-term effectiveness and stability of placement near active berthing areas is highly uncertain because of propeller wash (propwash) but was assumed to be stable for the purpose of this analysis.

Area 4

The fourth area includes 18 acres of structural slope and offset areas where dredge depths will be limited by the geotechnical stability of adjacent slopes (see Figures 1 and 2). In these areas, some contaminated sediment will be left behind; however, these elevation constraints are assumed to still allow the placement of a full RMC layer (i.e., average 9-inch-thick sand layer). The concentration immediately following completion of construction was estimated to be 35 µg/kg dw for total PCBs based on the dredging residuals methodology presented in Appendix B, Part 3A, of the FS.

Area 5

The fifth area includes 2.4 acres under the West Seattle Bridge and the bridge at the head of Slip 27 that have access restrictions (Figure 1). In these areas, removal is limited by geotechnical and structural considerations required to maintain stability of bridge columns. However, these areas are not limited in the amount of clean cover that could be placed following dredging. In addition, these areas experience little to no sediment disturbance from propwash. The resulting post-construction concentration was estimated to be 10 µg/kg dw for total PCBs through limited removal and RMC placement.

Area 6

The sixth area includes 1.8 acres under the three low bridges in the Sill Reach (Figure 1). These areas are characterized by extreme access limitations and widespread debris. Diver-assisted hydraulic dredging would be ineffective in these areas due to the presence of debris. Therefore, enhanced natural recovery (ENR) was assumed in these areas, with a post-construction concentration of 8 µg/kg dw, as a result of some dredging residuals depositing from adjacent areas consistent with the conceptual site model of sediment transport in the EW.

Considering all of these areas together, the site-wide SWAC immediately following construction was estimated to be 57 µg/kg dw for total PCBs, with an effective bioavailable concentration of 34 µg/kg. Recognizing this evaluation has uncertainties inherent to modeling, under this hypothetical maximum remediation scenario, the post-construction SWAC would not achieve the natural-background-based SCO for total PCBs. As discussed above, this hypothetical SWAC assumes that construction would be completed uniformly across the site, at a single point in time (e.g., instantaneously), therefore, this analysis does not consider the sediment mixing and exchange or ongoing sediment deposition that would occur over the timeframe required to conduct this cleanup. Moreover, this hypothetical scenario would have a construction timeframe of more than 15 years, during which time sediments would be mixing due to vessel propwash. Accordingly, the above site-wide post-construction SWAC represents an idealized condition that is not likely to be achieved during remedy implementation.

4.1.2 Maintenance in the Long Term

This section describes four considerations for whether it would be technically possible to maintain the natural-background based SCOs for total PCBs and dioxin/furan in the long term, considering the lowest technically possible achievable concentration estimated in Section 4.1.1. The four considerations are as follows:

1. Predicted increase in the SWAC following sediment mixing and exchange between under pier and open-water sediment
2. Predicted future average concentrations in particulate matter entering the EW
3. Measured concentrations present in surface sediment at remediated sites proximal to the EW
4. Measured surface sediment concentrations in Elliott Bay

The first line of evidence is the box model site-wide SWAC predictions. Following construction, box model predictions of the site-wide SWAC for each of the remediation alternatives except no action increase in the short-term (e.g., year 5 following construction) as a result of sediment mixing and exchange between open-water and under pier sediments (see FS Appendix J). The box model predicts that concentrations will then gradually reduce toward the net incoming sediment concentrations over time, which are estimated to be above natural background-based cleanup levels and lowest technically possible achievable concentration for total PCBs and dioxins/furans (see next line of evidence). As indicated in FS Appendix J, the box model is based on a series of estimates, which were developed for the purposes of comparing alternatives. The box model output was particularly sensitive to certain input parameters, including the incoming Green-Duwamish sediment concentrations, bioavailability reductions from activated carbon treatment, and net sedimentation rates, all of which are uncertain.

The second line of evidence is the estimated concentration of incoming sediments. Table 2 provides the estimated average sediment input concentrations for the EW based on incoming solids from both upstream (including Green River and LDW) and EW lateral inputs. These concentrations were calculated using a weighted average of chemical concentrations based on inputs entering the EW from the Green/Duwamish River, resuspended LDW bedded sediment, and lateral inputs from both the LDW and EW (see FS Table 5-5). Average input concentrations do not incorporate concentrations that may come from the EW bed, including the dredge residuals that will be present following construction, and sediments in unremediated areas. Average input concentrations were developed for the base case (best estimate), low bounding, and high bounding runs, adjusted to account for additional source control for lateral inputs (i.e., combined sewer overflow [CSO] and storm water inputs) managed by source control programs (e.g., National Pollutant Discharge Elimination System [NPDES]), which may have permit conditions modified in the future to reduce COC inputs to the EW. These estimates do not consider ongoing efforts to reduce sources of contamination to the upper Duwamish/Green River watershed. For total PCBs, the average input concentrations ranged from 8 to 85 μg/kg dw, and for dioxin/furans the average input concentrations ranged from 2 to 8 ng TEQ/kg dw. The base case (best estimates) values for both total PCBs (45 μg/kg dw) and dioxins/furans (6 ng TEQ/kg dw) are well above the SCO concentrations for total PCBs (2 μg/kg dw), and marginally above the SCO for dioxins/furans (2 ng TEQ/kg dw).

The third line of evidence is the post-remediation surface sediment concentrations of four cleanup sites in relatively close proximity to the EW, which were selected as representative of the post-remediation concentrations that could be expected to be achieved in the long term. Table 2 summarizes post-remediation monitoring data for Pier 53-54, Lockheed Shipyard, Todd Shipyards, and Duwamish Diagonal (through 2012), as well as the form of remediation (dredging, capping, or ENR) used at each site. The surface sediment data range from 5 to 10 years post-remediation and represent the surface sediment concentrations that can be expected following dredging, capping, or ENR, as well as the influence of ongoing sedimentation from diffuse urban inputs. Mean concentrations from the above four datasets suggest that post-remediation concentrations in the EW could range from approximately 32 to 133 μg/kg dw for total PCBs and be approximately 5 ng TEQ/kg dw for dioxin/furans (data from Duwamish/Diagonal cap only), depending on the dataset considered. These concentrations exceed the natural background levels for total PCBs and dioxins/furans. The resultant ranges of concentrations from all four of the datasets suggest that it is not technically possible to maintain the PRG for total PCBs (2 μg/kg dw) and may or may not be possible to maintain the PRG for dioxins/furans (2 ng TEQ/kg dw) in the long term in this region of Puget Sound, including the EW. It is important to note that ongoing and future source control efforts or sediment remediation in the surrounding area within the watersheds may decrease observed concentrations of depositing sediment. Furthermore, the sediment dynamics in the locations represented by these studies differ from those of the EW.

The fourth line of evidence is surface sediment concentrations from Elliott Bay. These data represent ambient concentrations in Elliott Bay, which provides an estimate of deposited sediment from diffuse urban inputs that may influence expected long-term concentrations. While the EW is adjacent to Elliott Bay, sediment load from Elliott Bay to the EW is assumed to be negligible compared to other sources (Windward and Anchor QEA 2014). Elliott Bay is a much larger waterbody than the EW and has many other sources along the shoreline that could contribute higher concentrations to sediment. As shown in Table 2, inner Elliott Bay[5] samples had a mean total PCBs concentration of 153 µg/kg dw (2007 data), and the mean dioxins/furans concentration was 20 ng TEQ/kg dw (2007 data). Concentrations are higher when 90th percentile values are considered (274 µg/kg dw for total PCBs based on 2007 data). In outer Elliott Bay, mean total PCBs concentrations range from 28 µg/kg dw (2007 data) to 32 µg/kg dw (1991 to 2004 data), and the mean dioxins/furans concentration was 2 ng TEQ/kg dw (2007 data) (see Table 2). Concentrations are higher when 90th percentile values are considered (e.g., 53 µg/kg dw for total PCBs based on 2007 data). Post-remediation concentrations of total PCBs and dioxins/furans in sediment in the EW may be higher than these values because of its closer proximity to diffuse urban inputs, which are more represented by data from inner Elliott Bay.

In summary, all the lines of evidence that inform an evaluation of the concentrations that can be achieved in the long term in the EW indicate that the PRG will not likely be achieved or maintained. For total PCBs, the average concentrations are well above the PRG of 2 µg/kg dw, and the range of achievable concentrations for all lines of evidence is 9 to 153 µg/kg dw. For dioxins/furans, the average concentrations are above the PRG of 2 ng TEQ/kg dw, and the range of achievable concentrations for all lines of evidence is 1.7 to 20 ng TEQ/kg dw. Regional background concentrations, if determined, may fall within these ranges.

4.2 Net Adverse Environmental Impact

The second factor in determining an upward adjustment of the SCO-based cleanup level is the determination of net adverse impact on the aquatic environment, which takes into

[5] Inner Elliott Bay samples are generally defined as samples east of a line from Terminal 91 directly south to West Seattle. Outer Elliott Bay includes the samples west of the line. See the depiction in Appendix J, Figure J-3, of the LDW FS (AECOM 2012).

account "the short- and long-term positive effects on natural resources, habitat restoration, and habitat enhancement and the short- and long-term adverse impacts on natural resources and habitat caused by cleanup actions" (WAC 173-204-560(2)(a)(ii)(B)). This discussion encompasses certain hypothetical scenarios and lines of evidence that could be used as part of a net environmental impacts analysis and is presented for comparison purposes only.

The SMS cleanup levels for total PCBs and dioxin/furans that are not adjusted significantly upward from the PRG could only be met and reliably maintained with additional dredging over larger areas and at greater depths, and repeated capping and re-dredging of the same areas as concentrations rise due to diffuse source inputs over time. This approach would result in very large adverse impacts on the aquatic environment (natural resources and habitat) from construction without producing any countervailing long-term environmental benefits from the additional cleanup measures (i.e., risk reduction). Repeated rounds of dredging and/or capping would result in major additional construction-related adverse impacts to the benthic community, due to disruption of the established biological active zone, and to fish tissue contaminant levels, due to releases of contaminated material during dredging, resulting in higher fish exposures. In addition, these adverse impacts would occur over a significantly longer period of time. Even with ongoing efforts of this type, evidence presented in Section 4.1 of this appendix suggests that the PRGs for total PCBs and dioxin/furans would still not be achieved. As such, the continued cleanup activities in an attempt to reach concentrations closer to the PRG would result in significant adverse impacts to the environment without commensurate benefits to the benthic community or reductions in tissue concentrations that would lower human health risks. Ultimately, the EW system will equilibrate to incoming sediment concentrations that are estimated to be higher than the PRG and similar to concentrations resulting from less disruptive cleanup activities associated with higher cleanup levels (e.g., CSL).

In comparison, the SMS cleanup levels based on the CSL for total PCBs and dioxin/furans (i.e., regional background, if established) would result in slightly smaller adverse impacts on the aquatic environment from construction because the cleanup technologies needed to meet the cleanup levels would be less intrusive to benthic communities in some areas (less dredging or capping), and the need for additional contingency actions would be greatly reduced or eliminated. A cleanup level at or close to a potential regional background concentration for total PCBs and dioxin/furans, if established, would reflect the concentrations of those contaminants in incoming sediment over the long term, thereby avoiding unnecessary adverse impacts on the aquatic environment from construction and ultimately resulting in similar or improved long-term environmental benefits from cleanup (i.e., risk-reduction). Therefore, sediment cleanup levels based on the PRG will result in net adverse impacts, which would likely not occur with cleanup levels that are adjusted upward to the CSL based on regional background.

4.3 Summary and Conclusion

Compliance with the SMS and CERCLA PRGs will likely involve the adjustment of cleanup levels upward from the SCO (PRG) to the CSL for total PCBs and dioxins/furans. This adjustment may occur in the future if the CSL (i.e., a regional background value applicable to the EW Superfund site) is established by EPA for these contaminants.

For FS purposes, a hypothetical maximum remediation scenario was analyzed to approximate lowest technically-possible concentrations for total PCBs that could be achieved following construction. While this analysis is subject to uncertainty, it indicated that approximately 57 μg/kg dw could be achieved (34 μg/kg when making adjustments for bioavailability) when considering limitations to remediating near structures to achieve very low total PCBs concentrations.

Multiple lines of evidence were evaluated to approximate values that could be achieved in the long term. For total PCBs, the average concentrations are above the PRG of 2 μg/kg dw, and the range of achievable concentrations for all lines of evidence is 9 to 153 μg/kg dw. For dioxins/furans, the average concentrations are above the PRG of 2 ng TEQ/kg dw, and the range of achievable concentrations for all lines of evidence is 1.7 to 20 ng TEQ/kg dw. As discussed in Section 4, under the SMS, the cleanup level may not be adjusted above the CSL (i.e., regional background values, if established by EPA).

Finally, a hypothetical possible scenario for considering the net adverse environmental impact for setting the cleanup level at the SCO was qualitatively discussed, indicating that the cleanup levels would likely need to be adjusted upward to the CSL, if established, to avoid environmental disturbances that result in no environmental benefit.

As noted above, this analysis was developed for FS purposes only; it contains assumptions about future conditions that are inherently uncertain. While CERCLA does not require that a technical possibility evaluation be conducted in the FS, it provides additional information that EPA could consider for a potential future adjustment of cleanup levels or TI waiver.

5 SEDIMENT RECOVERY ZONE

Under SMS, a restoration timeframe of longer than 10 years (i.e., cleanup levels not achieved within 10 years) would result in the designation of an SRZ (WAC 173-204-570(5)(b)). SMS define the SRZ as the following:

> *"Sediment recovery zone" means an area authorized by the department within a site or sediment cleanup unit where the department has determined the cleanup action cannot achieve the applicable sediment cleanup standards within ten years after completion of construction of the active components of the cleanup action.*

The SRZ is used to track a cleanup area that remains above cleanup levels and perform additional cleanup or source control actions as necessary. The requirements of the SRZ are listed in WAC 173-204-590(2) and are very similar to the CERCLA requirements for a selected remedy. EPA may consider the substantive criteria for an SRZ, WAC 173-204-590(3), when determining the reasonable restoration timeframe of the remedial action for the EW. The remaining portion of the discussion of SRZs under the SMS is presented for comparison purposes only.

The key components of the SRZ approach, if used, are the following:

- The SRZ could be designated side-wide for relevant human health risk drivers 10 years following construction.
- 5-year reviews and site-wide monitoring program could provide the periodic review process for adjusting, eliminating, or renewing the SRZ consistent with the SMS.
- The SRZ could be used in concert with active cleanup and source control measures for the selected alternative and would not replace cleanup actions. The contaminant concentrations within the SRZ will be as close as practicable to the cleanup level, based on the CERCLA comparison of alternatives under the nine criteria in the FS.

Post-construction site-wide monitoring data will be used to evaluate progress toward meeting the cleanup levels. This information could also be used to support establishment or evaluation of regional background concentrations and potential modification of the SRZ, if established by EPA, and closure of the EW OU.

If monitoring data shows cleanup standards cannot be met, the following options are available for Ecology to consider:

1. *If noncompliance is due to PLP sources not being controlled, additional source control may be necessary.*
2. *If noncompliance is due to contribution from other sources that are not under the responsibility or authority of the PLP, closure of the SRZ may be appropriate or adjustment of the cleanup level may be appropriate. For example:*
   a. *Ecology may consider whether the cleanup level should be adjusted upwards according to the process detailed in Chapter 7, Section 7.2.3. An example of when this may be appropriate is where the cleanup level was established below regional background, but Ecology has since established or approved regional background for the geographic area where the site is located. In this case, Ecology may determine that regional background represents the concentration in sediment that is technically possible to maintain, due to ongoing sources that are not under the authority or responsibility of the PLP. Therefore, Ecology could allow upwards adjustment of the sediment cleanup level to the CSL if regional background has been established as the CSL.*
   b. *If the cleanup levels are based on background (regional or natural), Ecology will consider whether background concentrations have increased, and the cleanup level should be adjusted upwards.*

(Ecology 2017, Section 14.2.6)

6 CONCLUSIONS

The PRGs in the EW FS have been developed under CERCLA to be consistent with the SMS (WAC 173-204-560). The selected alternative will meet the SMS ARAR over time in one of two ways: 1) by achieving the SCO in a reasonable restoration timeframe, as determined by EPA; or 2) by achieving the cleanup level in a reasonable restoration timeframe, as determined by EPA, after the establishment of a CSL and upward adjustment of the cleanup level. If cleanup levels are not achieved within a reasonable restoration timeframe, the SMS ARAR may be met through compliance with the substantive criteria of an SRZ (WAC 173-204-590(3)), potentially including determination by EPA of whether an extension of the restoration timeframe is appropriate.

Because it is not known whether, or to what extent, the SMS ARARs for various COCs will be achieved in the long term, or the timing of a potential regional background evaluation, the way in which the cleanup will comply with SMS (described above as meeting either the natural background PRG in a reasonable restoration timeframe, or by upwardly adjusting the cleanup level to regional background and meeting it in a reasonable restoration timeframe), is not selected at this time. The method used to comply with the SMS ARAR will depend primarily on the timing of regional background evaluations for the EW and measured remedial action performance following construction.

EPA may also issue a TI waiver at some point in the future if EPA determines that SMS-based cleanup levels cannot be practicably achieved within the EW.

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TABLES

Table 1
Areas and Post-construction Concentrations for Maximum Possible Remediation Evaluation

Area		Area (acres)	Remediation and Residuals Management Approach	Residuals PCBs Concentration (µg/kg dw)	Residuals Thickness (cm)	Resulting Post-construction Concentration	Notes
1	Open-water Areas Away from Offsets, Slopes, and Riprap	114	Two cleanup dredging passes and RMC	141	5.8	10	Residuals concentration and thickness based on residuals approach discussed in WPAM 1, but with two cleanup passes followed by RMC.
2	Underpier Areas	15	Diver-assisted hydraulic dredging followed by in situ treatment	510	10	290 µg/kg dw; 153 µg/kg effective bioavailable	Residuals concentration and thickness based on the Draft FS assumption for dredging down to riprap surface. Post-construction concentration based on volume-weighted average concentration under the pier (510 µg/kg), with a 70% reduction in bioavailability.
3	Keyways	7.0	Dredging to the extent practicable followed by in situ treatment[a]	640	10	364 µg/kg dw; 192 µg/kg effective bioavailable	Residuals concentration and thickness based on the Draft FS assumption for dredging down to riprap surface. Post-construction concentration based on the estimated site-wide average last-pass dredging concentration (760 µg/kg), with a 70% reduction in bioavailability.[a]
4	Structural Slope and Offset Areas	18	Dredging to the extent practicable with RMC	640	5.1	35	Residuals concentration, thickness, and post-construction concentration based on residuals approach discussed in WPAM 1.
5	Under the West Seattle Bridge and the Head of Slip 27 Bridge	2.4	Dredging to the extent practicable with RMC	640	10	10	Residuals concentration based on site-wide average concentration in the last dredging production pass (presented in WPAM 1). Residuals thickness incorporates offsets from bridge structures. Post-construction concentration is assumed to be 10 µg/kg based on minimal resuspension in the relatively quiescent conditions between the low bridges.
6	Under Low Bridges	1.8	Enhanced natural recovery (ENR) (dredging not possible due to access and debris)	640	1.0	8	Area is characterized by large debris and poor access. Dredging would be ineffective without bridge removal. Assume that ENR is used with a post-construction concentration based on a 1-cm residuals thickness from neighboring dredging.
Site-wide Area-weighted Average		157	Varies	262	Varies	57 µg/kg dw; 34 µg/kg effective bioavailable	Site-side SWAC based on the post-construction concentrations and areas above.

Notes:
a. The hypothetical placement of in situ treatment material in keyways is presented for this evaluation. However, some keyway areas are already at the required navigation elevation and placement types/thickness may be limited by the navigation requirements. In addition, long term effectiveness and stability of placement in active berthing areas is highly uncertain because of prop-wash. Reduction in bioavailability is approximated.
µg/kg - microgram per kilogram
cm - centimeter
dw - dry weight
FS - Feasibility Study
PCB - polychlorinated biphenyl
RMC - residuals management cover
SWAC - spatially-weighted average concentration
WPAM - Work Product Approval Meeting

Table 2
Technical Possibility Lines of Evidence

Location	Area Description	PCBs (µg/kg dw) Average (points)	PCBs Median	PCBs 90th Percentile	PCBs n	Dioxin/Furan (ng TEQ/kg dw) Average (points)	Dioxin/Furan Median	Dioxin/Furan 90th Percentile	Dioxin/Furan n	Notes	Citation
East Waterway Input Concentrations											
East Waterway	Weighted average input concentrations (base case)	45	n/a	n/a	n/a	6	n/a	n/a	n/a	From Table 5-5 of the East Waterway Feasibility Study. Methods described in Section 5.3.2 of the Feasibility Study. Based on future conditions.	n/a
	Weighted average input concentrations (low bounding)	9	n/a	n/a	n/a	2	n/a	n/a	n/a		
	Weighted average input concentrations (high bounding)	85	n/a	n/a	n/a	8	n/a	n/a	n/a		
Sediment Remediation Sites											
Pier 53-55, Elliott Bay	Post-remediation cap and ENR surface	32	15	68	7	n/a	n/a	n/a	n/a	Sampled in 2002, year 10 post-remediation (capping and ENR).	King County 2010
Lockheed, Shipyard No. 1, West Waterway	All open channel remediation areas (dredge with/without ENR)	133	102	202	5	n/a	n/a	n/a	n/a	Sampled in 2012, year 7 post-remediation (removal and removal with ENR). Beach samples excluded. Five samples from upper 10 cm.	Tetra Tech 2012
Todd Shipyards, West Waterway	All remediation areas (dredge with/without ENR, capping)	78	44	106	15	n/a	n/a	n/a	n/a	Sampled in 2010, 5 years post-remediation (mixture of open-water dredging, some dredging with ENR, and underpier and nearshore capping).	Floyd|Snider 2010
Duwamish Diagonal, Lower Duwamish Waterway	Caps A and B	54	55	90	8	5.1	5.1	6.6	3	Sampled in 2009, event year 6 post-remediation (capping).	AECOM 2012 (Feasibility Study report and database)
Elliott Bay Concentrations											
Elliott Bay	All of Elliott Bay from 2007 sampling	119	63	250	18	15	5.9	37	18	All Elliott Bay samples in the 0-10 cm interval collected in 2007. Both Outer Elliott Bay data and Inner Elliott Bay as defined by the report.	Ecology 2008
	Inner Elliott Bay only from 2007 sampling	153	184	274	13	20	6.5	73	13	13 samples from the 0-10 cm interval collected in 2007. Inner Elliott Bay as defined in the report.	
	Outer Elliott Bay only from 2007 sampling	28	17	53	5	1.7	1.6	2.9	5	Elliott Bay in the 0-10 cm interval collected in 2007. Outer Elliott Bay as defined in the report.	Ecology 2008
	Outer Elliott Bay only from 1991-2004 sampling events	38	17	82	28	n/a	n/a	n/a	n/a	Data from 1991 to 2004 from EIM database. Inner and Outer Elliott Bay as defined in the report.	AECOM 2012 (Feasibility Study Table J-1)

Notes:

µg/kg - microgram per kilogram
cm - centimeter
dw - dry weight
ENR - enhanced natural recovery
n/a - data not available or parameter not applicable
ng TEQ/kg - nanogram toxic equivalent per kilogram
PCB - polychlorinated biphenyl
Statistics were performed in Excel using standard equations.

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FIGURES

Q:\Jobs\060003-01 East Waterway SRI-FS\Analysis\2015_08_Max_Alternative\Max_Remed_Areas_Offsets.mxd ckiblinger 1/19/2016 11:14:21 AM

CMA Boundaries
Riprap (No Action)
1 - Unrestricted Dredging Areas
2 - Underpier Areas
3 - Keyway Areas
4 - Structural Slope and/or Offset Areas
5 - Underbridge Areas with Equipment Access
6 - Low Bridges without Access for Dredge Equipment

NOTES:
Maximum possible sediment removal does not include demolition and reconstruction of structures or structural slopes in the East Waterway.

0 500 1,000
Scale in Feet

Figure 1
Areas and Offsets for Maximum Possible Remediation Evaluation
Feasibility Study - Appendix A
East Waterway Study Area

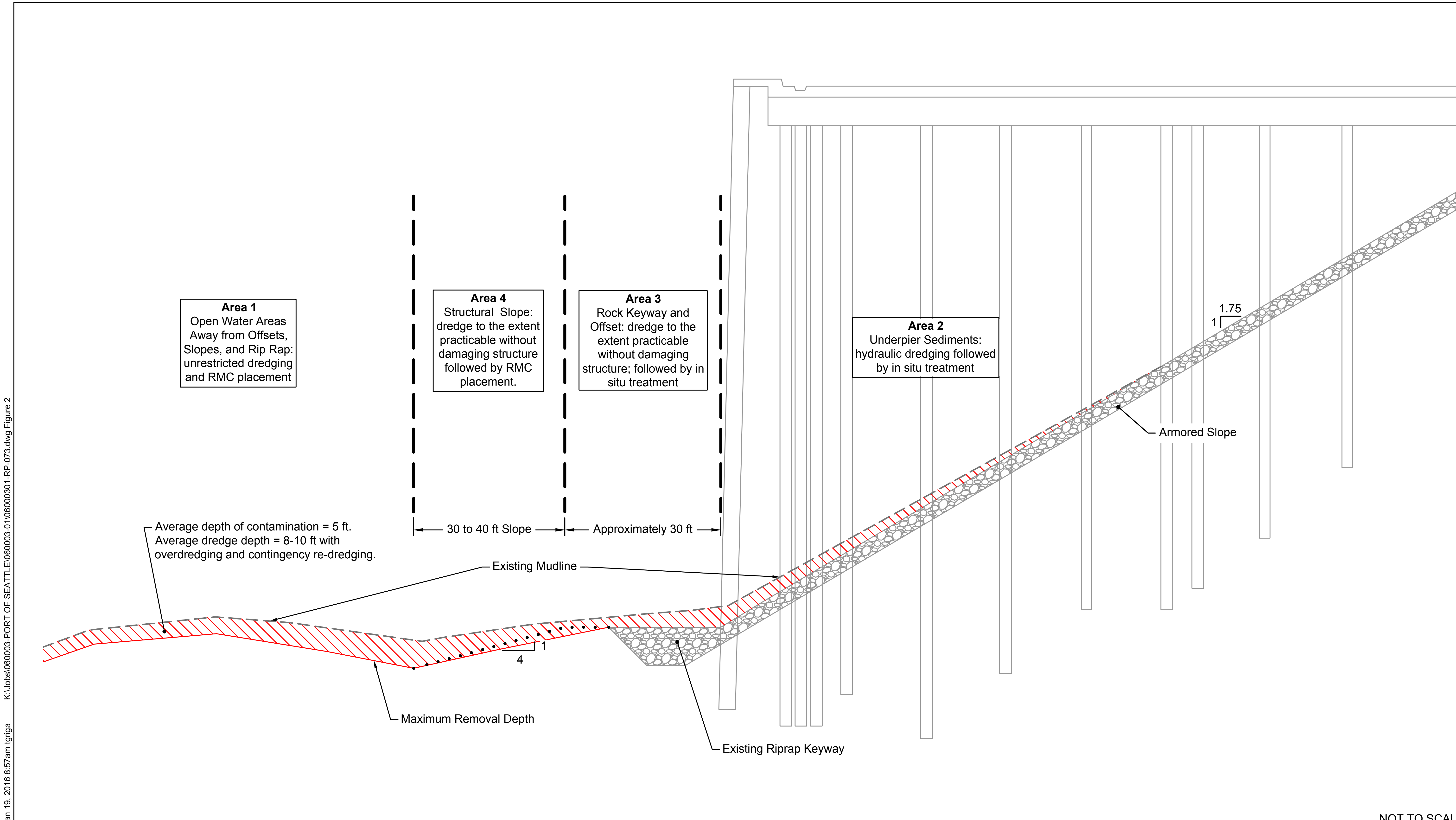

Figure 2
Conceptual Cross Section Showing Maximum Possible Remediation for East Waterway Terminal with Keyway
Feasibility Study - Appendix A
East Waterway Study Area

PART 2: DEVELOPMENT OF SEDIMENT PRGS FOR PCBS IN FISH

Development of Sediment PRGs for PCBs in Fish

Total PCBs were identified in the Baseline Ecological Risk Assessment (ERA) for the East Waterway (EW) site as a contaminant of concern (COC) for English sole and brown rockfish because PCBs in tissues of both fish species exceeded the two lowest observed adverse effect level (LOAEL) toxicity reference values (TRVs) that were associated with adverse effects in fish. Total PCBs were also identified as a risk driver COC for fish based fish tissue concentrations exceeding the higher LOAEL TRV(Windward 2012).

Two LOAEL TRVs for fish were evaluated in the ERA for PCBs because of uncertainties associated with the lowest LOAEL TRV. Both TRVs are derived from Hugla and Thome (1999). The study examined the effects of PCB exposure on reproductive endpoints with fish dosed at two concentrations. During the first reproductive season there was no spawning at the high exposure, and no adverse effects were reported for the lower exposure level. One year following exposure, significant reductions in fecundity were reported at both exposure levels. The fecundity LOAEL associated with the lower dose is uncertain because fecundity as measured after the first two spawning seasons was not dose-responsive. Egg mortality was significantly higher than the control in the higher exposure level but at the lower dose, egg mortality was not significantly different from controls. The uncertainties in this study are detailed in the ERA uncertainty analysis (Section A.6.2.2.2). Uncertainties discussed include those associated with the statistical analysis for the fecundity endpoint and the fact that this endpoint was not dose responsive, uncertainties related to test conditions, and uncertainties in the estimate of the whole-body concentration associated with effects. Total PCBs in fish was the only COC that was evaluated based on two TRVs. In the EW Supplemental Remedial Investigation (SRI), the two TRVs were used to derive two tissue risk based threshold concentrations (RBTC) values from which two sediment RTBC values are derived.

A sediment PRG value for each fish species is needed to evaluate the effectiveness of proposed remediation strategies in the FS. This memo provides the basis for the development of a sediment PRG value for each fish receptor for total PCBs. As discussed in Section 4 of the FS, PRGs are developed based on an evaluation of RBTCs, background concentrations and practical quantitation limits. The analysis presented sediment RBTCs for fish that are above background concentrations for total PCBs and above practical quantitation limits (see Section 4 in the FS), and therefore, the RBTCs are used to set the sediment PRG for total PCBs for fish. Because of the uncertainties in the lower TRV (see ERA Sections A.6.2.2.2), the lower TRV was not used alone to develop the sediment PRG for fish. Instead, two approaches were evaluated for the development of the PRG value, both of which included the use of the lower TRV in combination with other TRVs. The first approach is based on the mean of the tissue

RBTC values from the EW SRI (Anchor and Windward 2013). The second approach is based on the calculation of the 5th percentile of the ERA effects dataset.

The first approach to deriving a sediment PRG for each fish receptor was to use the mean of the two tissue RBTC values (0.52 and 2.64 mg/kg ww) for PCBs in fish. This approach results in a tissue value of 1.6 mg/kg ww, which was then used to derive sediment values for both English sole and brown rockfish using the site-wide EW PCB food web model (FWM). This approach resulted in sediment values of 370 µg/kg dw for English sole and 250 µg/kg dw for brown rockfish.

The second approach was to calculate a percentile value of the TRV dataset for PCBs in fish tissue that was developed in the ERA (Windward 2012). The calculation of a low percentile value from a dataset of acceptable studies of effects is consistent with the approach used in developing ambient water quality criteria (Stephan et al. 1985) and other criteria developed for the protection of special-status species (e.g., Meador et al. 2002).

Thirteen studies with fish tissue LOAELs for the potential adverse effects of PCB mixtures on fish were reviewed in the ERA (Table 1). None of the studies used English sole or brown rockfish. Concentrations of PCBs in fish tissue were reported in 17 species (i.e., Atlantic croaker, Atlantic salmon, brook trout, channel catfish, coho salmon, common barbel, fathead minnow, goldfish, Chinook salmon, pinfish, rainbow trout, mummichog, sheepshead minnow, common minnow, and spot). Adverse effects included reduced body weight; reduced early life stage or fry growth and survival; and reduced fecundity, hatchability, and spawning success following exposure to PCBs.

Whole-body effect-level concentrations ranged over three orders of magnitude across the fish species included in the toxicological studies. Whole-body tissue LOAELs ranged from 0.520 mg/kg ww for reduced barbel fecundity (Hugla and Thome 1999) to 749 mg/kg ww for mortality of fathead minnows (van Wezel et al. 1995).

All LOAEL values were included in the derivation of the percentile value except the results of one study (Table 1). The LOAEL values from van Wezel et al. 1995 were excluded because of the lack of a control in the study design and large variability in the results.

Table 1. Fish whole-body tissue-residue TRVs for PCBs from the EW ERA

Chemical	Test Species	Tissue Analyzed	Whole-body NOAEL (mg/kg ww)	Whole-body LOAEL (mg/kg ww)	Effect	Source	Acceptable for derivation of 5th percentile LOAEL
Aroclor 1260	common barbel	whole body	na	0.520[a]	reduced fecundity	Hugla and Thome (1999)	Yes
Aroclor 1254	juvenile Chinook salmon	whole body	0.980	na	no effect on growth or survival	Powell et al. (2003)	LOAEL na
Aroclor 1260	common barbel	whole body	0.520[b]	2.64[a]	lack of spawning in first reproductive season; egg and larval mortality	Hugla and Thome (1999)	Yes
Aroclor 1254	rainbow trout (14 weeks)	whole body	8.0	na	no effect on growth or survival	Lieb et al. (1974)	LOAEL na
Aroclor 1254	sheepshead minnow (adult)	whole body	1.9	9.3	decreased fry survival in the first week after hatch	Hansen et al. (1974a)	Yes
Aroclor 1254	pinfish	whole body	na	14	reduced survival	Hansen et al. (1971)	Yes
Aroclor 1268	mummichog (adult)	whole body	15	na	no effect on fertilization, hatching, or larval survival	Matta et al. (2001)	LOAEL na
Clophen A50	common minnow	whole body	na	25	reduction in time to hatch, fry mortality	Bengtsson (1980)	Yes
Aroclor 1260	channel catfish	whole body	32	na	no effect on growth or survival	Mayer et al. (1977)	LOAEL na
Aroclor 1254	spot	whole body	27	46	reduced survival	Hansen et al. (1971)	Yes
Aroclor 1260	fathead minnow	whole body	na	50	reduced offspring body weight	DeFoe et al. (1978)	Yes
Aroclor 1254	brook trout embryos	whole body	31	71[c]	reduced fry growth	Mauck et al. (1978)	Yes
Aroclor 1016	sheepshead minnow	whole body	77	na	no effect on fertilization success, survival of embryos, or fry survival	Hansen et al. (1975)	LOAEL na
Aroclor 1016	pinfish	whole body	na	106	50% mortality	Hansen et al. (1974b)	Yes
Aroclor 1254: 1260 mixture	juvenile rainbow trout	whole body	120	na	no effect on survival	Mayer et al. (1985)	LOAEL na

Chemical	Test Species	Tissue Analyzed	Whole-body NOAEL (mg/kg ww)	Whole-body LOAEL (mg/kg ww)	Effect	Source	Acceptable for derivation of 5th percentile LOAEL
Aroclor 1254: 1260 mixture	juvenile rainbow trout	whole body	70	120	reduced growth	Mayer et al. (1985)	Yes
Aroclor 1254	brook trout embryos	whole body	71	125	reduced fry survival	Mauck et al. (1978)	Yes
Aroclor 1254	fathead minnow	whole body	na	196 (male)	reduced spawning	Nebeker et al. (1974)	Yes
Aroclor 1016	sheepshead minnow fry	whole body	77	200	reduced fry survival	Hansen et al. (1975)	Yes
Clophen A50	goldfish	whole body	na	250	lethal body burden	Hattula and Karlog (1972)	Yes
Aroclor 1242, 1254, or 1260	fathead minnow (6 months)	whole body	na	1.86 – 749	range of lethal body burdens (concentration associated with mortality of individuals)	van Wezel et al. (1995)	No

[a] Whole-body NOAELs and LOAELs were estimated using egg-to-adult conversion factors for studies that reported concentrations in eggs rather than whole-body tissue.

[b] Whole-body tissue residues were the weighted sum of 10 different tissues (i.e., blood, brain, muscle, skin, liver, gonads, adipose tissues, kidney, digestive tract, and skeleton) (Leroy 2007). Tissue concentrations were converted from dry weight to wet weight assuming 20% solids; all endpoints except first reproductive season spawning were evaluated 1 year after exposure.

[c] At the LOAEL, growth was significantly less than control at 48 days after hatching but not at 118 days after hatching. At NOAEL and LOAEL concentrations, study provides tissue concentrations only after 7 days and 118 days of exposure. LOAEL and NOAEL are tissue concentrations in fry at 118 days post hatch. Tissue concentrations at 7 days post-hatch associated with no effects (1.8 mg/kg ww) and low effects (3.2 mg/kg ww) were lower than the concentration at 118 days post-hatch.

ERA – Ecological Risk Assessment
EW – East Waterway
LOAEL – lowest-observed-adverse-effect level
na – not available
NOAEL – no-observed-adverse-effect level
PCB – polychlorinated biphenyl
TRV – toxicity reference value
ww – wet weight

The 5^{th} percentile LOAEL value was calculated using fourteen whole-body LOAEL values from the ERA TRV dataset (Table 2). The 5th percentile of the LOAEL values is 1.9 mg/kg ww (Figure 1).

Table 2: LOAEL values used in calculation of 5th percentile LOAEL

Source	Whole-body LOAEL (mg/kg ww)
Hugla and Thome (1999)	0.520
Hugla and Thome (1999)	2.64
Hansen et al. (1974a)	9.3
Hansen et al. (1971)	14
Bengtsson (1980)	25
Hansen et al. (1971)	46
DeFoe et al. (1971)	50
Mauck et al. (1978)	71
Hansen et al. (1974b)	106
Mayer et al. (1985)	120
Mauck et al. (1978)	125
Nebeker et al. (1974)	196
Hansen et al. (1975)	200
Hattula and Karlog (1972)	250

LOAEL – lowest-observed-adverse-effect level
ww – wet weight

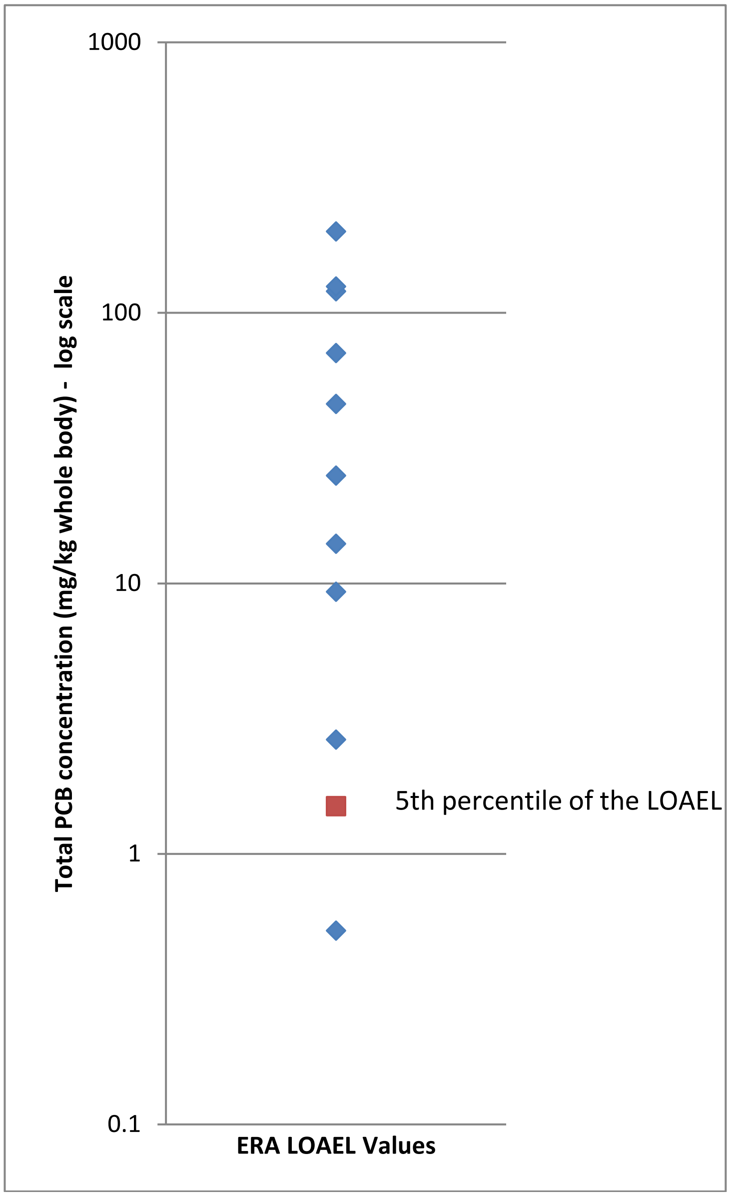

Figure 1: LOAEL TRV values and 5th percentile value

The tissue value of 1.9 mg/kg ww was then used to derive sediment values for both English sole and brown rockfish using the site-wide EW FWM for PCBs. This approach resulted in sediment values of 450 µg/kg dw for English sole and 280 µg/kg dw for brown rockfish.

The sediment values derived from the mean of the tissue RBTCs and the 5th percentile of the tissue TRV dataset are provided in Table 3. The values are within a factor of two of each other, which is within the bounds of food web model predictability (typically within a factor of 2 to 5). Because these values are subject to all the uncertainties associated with the food web model, the sediment values are not considered significantly different from one another. Based on this analysis and considering the uncertainties in the lowest LOAEL TRV, the sediment PRGs for fish are derived based on the sediment values calculated from the mean of the two tissue RBTCs. These values are above background sediment concentrations for PCBs (see Section 4 of the FS) as well as practical quantitation limits. Therefore, the sediment PRG for English sole is 370 µg/kg dw and the sediment PRG for brown rockfish is 250 µg/kg dw.

Table 3: Total PCBs Sediment PRG values for English sole and brown rockfish

Fish ROC	Sediment value(µg/kg dw) based on mean of tissue RBTCs	Sediment value (µg/kg dw) based on 5th percentile of TRV dataset	Selected Fish Sediment PRG
English Sole	370	450	**370**
brown rockfish	250	280	**250**

µg/kg dw – microgram per kilogram dry weight
PRG – preliminary remediation goal
RBTC – risk-based threshold concentration
ROC – receptor of concern
TRV – toxicity reference value

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APPENDIX B – SEDIMENT MODELING MEMORANDA

EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

Prepared for

Port of Seattle

Prepared by

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June 2019

APPENDIX B TABLE OF CONTENTS

PART 1: ADDITIONAL SEDIMENT TRANSPORT MODELING

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List of Figures

Attachments

LIST OF ACRONYMS AND ABBREVIATIONS

3-D	three-dimensional
BMP	best management practice
City	City of Seattle
cm	centimeter
County	King County
CSO	combined sewer overflow
DMR	Discharge Monitoring Report
EFDC	Environmental Fluid Dynamics Code
EW	East Waterway
FS	Feasibility Study
ISGP	Industrial Stormwater General Permit
kg	kilogram
LDW	Lower Duwamish Waterway
m^3	cubic meter
NPDES	National Pollutant Discharge Elimination System
Port	Port of Seattle
PTM	particle tracking model
SD	storm drain
SRI	Supplemental Remedial Investigation
STE	sediment transport evaluation
STER	Sediment Transport Evaluation Report
SWAC	spatially-weighted average concentration
TSS	total suspended solids

1 PURPOSE OF ADDITIONAL SEDIMENT TRANSPORT MODELING

The spatial distribution of sediments deposited within the East Waterway (EW) from lateral sources (i.e., storm drain [SD] and combined sewer overflow [CSO] outfalls located along the length of the EW) was estimated using the particle tracking model (PTM) developed by the U.S. Army Corps of Engineers (USACE; McDonald et al. 2006). The purpose of the PTM effort was to inform the Physical Conceptual Site Model developed in the EW Supplemental Remedial Investigation (SRI; Windward and Anchor QEA 2014) and to provide information that could be used to evaluate site trends over time following remediation and the potential for recontamination in the EW Feasibility Study (FS) due to sediment loads from identified lateral sources within the EW.

The initial modeling effort, discussed in the EW Sediment Transport Evaluation Report (STER; Anchor QEA and Coast & Harbor Engineering 2012), was completed using current conditions solids loads for EW lateral sources as inputs to the PTM. Three scenarios were evaluated for current conditions solids loads: a base case (best estimate), and high and low bounding cases based on 25th and 75th percentile total suspended solids (TSS) data. The development of these solids loads are discussed in detail in Section 7.2 and Appendix F of the STER. The additional modeling effort conducted as part of this FS, and discussed in this appendix, was completed to assess projected future conditions solids loads for EW lateral sources. As with the initial modeling work, a base case (best estimate) and high and low bounding cases for solids loads were evaluated. The purpose of this additional modeling effort was to provide information to evaluate site performance over time and recontamination potential in the EW (post-construction) considering future source control efforts.

This appendix provides information about the estimation of solids inputs from EW lateral sources (SDs and CSOs) for likely future conditions and the results of the PTM based on projected future conditions. The development of chemistry assumptions, methodology for using the results of the PTM to complete the site performance and recontamination potential evaluation, and results of the recontamination potential evaluation are provided in Sections 5 and 9 and Appendix J of the FS.

2 OVERVIEW OF INITIAL MODELING APPROACH

The initial modeling effort was completed as part of the sediment transport evaluation (STE) and is discussed in detail in Section 4 (hydrodynamic model) and Section 7 (PTM) of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012). A brief overview of the technical approach is provided in this section. This approach reflects previously approved methods used in the STER. Development of solids loads from EW lateral sources (SDs and CSOs) for current and future conditions is discussed in Section 3 herein, and results of the additional PTM effort are provided in Section 4.

The PTM uses a Lagrangian method to simulate the transport of discrete particles within the modeling domain (McDonald et al. 2006). The PTM uses the output from the hydrodynamic model (e.g., current velocities) to simulate the transport of suspended particles (from lateral sources) within the EW. The hydrodynamic model utilized in the EW STE was developed through modification of an existing model used to evaluate hydrodynamics in the Lower Duwamish Waterway (LDW; Windward and QEA 2008). The model utilizes the three-dimensional (3-D) Environmental Fluid Dynamics Code (EFDC) computer code to represent hydrodynamic processes. It is a physics-based model in that it includes the important physical processes and algorithms to describe the hydrodynamic processes in the system. The model domain extends from the Duwamish River at the south to a boundary between Puget Sound and Elliott Bay that is located between Alki Point and West Point. The LDW hydrodynamic model was updated as part of the EW STE to increase the grid resolution within the EW (see Figure 1[1]) and calibrated with data from the EW. The hydrodynamic model simulations used as input to the PTM included a constant inflow at the upstream boundary equal to the mean annual flow[2], and tidal downstream boundary conditions using representative spring tide conditions[3]. The mean annual flow and spring tide conditions were used to represent annual average hydrodynamic conditions in the EW (see Section 7.3.1 of the STER; Anchor QEA and Coast & Harbor Engineering 2012).

[1] Figure 1 shows the model grid within the EW only. The complete model grid extends to the north and south of the EW.
[2] Mean annual flow is 1,330 cubic feet per second based on data from the U.S. Geological Survey gage at Auburn, Washington.
[3] Tidal elevations were taken from verified 6-minute data from the National Oceanic and Atmospheric Administration tide station in Elliott Bay (#9447130) from June 1 to July 31, 2009.

The PTM tracks the path particles may travel in the water column from the time of particle release at the source location until the particle is deposited on the sediment bed or leaves the model domain. Particles are released into the flow field at their discharge location with no incoming plume velocity; therefore, the initial velocity of the particle within the model is solely dictated by the hydrodynamic model results at the discharge location. The PTM tracks the movement of parcels of sediment with a set mass, as opposed to individual particles. The parcel size was set to 0.5 kilogram (kg) for all simulations, and the standard deviation of the particle size distribution was set to 0.8 φ[4]. These values are commonly accepted values for this application (McDonald et al. 2006) and were validated through a sensitivity analysis completed as part of the EW STE.

The particle deposition predicted by the PTM represents the initial deposition of the particles within the EW and does not take into account resuspension of the particles due to current velocities or vessel operations (e.g., propeller wash [propwash]). Resuspension processes in the PTM were not included in the simulations because:

- Resuspension of sediments due to tidal and riverine currents is expected to be small, due to low predicted near-bed currents in the EW (see Section 6 of the STER; Anchor QEA and Coast & Harbor Engineering 2012).
- Resuspension of sediments in the EW is dominated by vessel activity (propwash). The hydrodynamic model does not include the prediction or influence of vessel induced currents; therefore, resuspension from these activities cannot be modeled numerically with the PTM. In addition, the influence of vessel wakes was not modeled. The influence of vessel wakes is confined to the shallow water areas of the site, which are primarily engineered surfaces (e.g., riprap without accumulated sediment).

The effect of resuspension on sediment deposition is to redistribute (i.e., mix) depositing sediment. Therefore, the PTM shows more localized and concentrated deposition (i.e., closer to outfalls) than expected in the EW when considering resuspension.

[4] Chosen parameters used for the modeling were determined through a sensitivity analysis conducted as part of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012).

The PTM is best suited for simulating relatively short-term sediment transport events such as discharge from outfalls, and resuspension due to dredging. Conducting a long-term, multi-year PTM simulation is impractical due to exceedingly long runtimes as increasing numbers of particles are created within the model. Thus, PTM simulations covering a shorter simulation time were conducted, and the results were assumed to be representative of long-term average conditions (based on input conditions, which were representative of annual average values). For both the initial and additional PTM effort, the model simulation time was set to 42 days total—28 days with solids being released into the EW and an additional 14 days with the mass flux into the EW set to 0 to allow finer particles in suspension to settle prior to the end of the simulation time period[5].

The results of the PTM simulations were post-processed within a GIS environment to produce maps of initial solids deposition (in kg and centimeters [cm] per year) within the EW from lateral sources (provided in Section 4 of this appendix). The solids deposition was combined with chemistry information to evaluate the potential for post-construction recontamination within the EW; chemistry assumptions and the recontamination evaluation are discussed in Section 4 and Appendix J of the FS.

[5] Additional information regarding the development, input data, and results for the hydrodynamic model and PTM can be found in Sections 4 and 7 of the EW STER, respectively (Anchor QEA and Coast & Harbor Engineering 2012).

3 FUTURE CONDITION INPUTS TO THE EAST WATERWAY

Lateral sources of sediment to the EW include SDs and CSOs. Currently, 39 outfalls (36 SDs, one CSO, and two CSO/SDs) to the EW have been identified (Anchor QEA and Windward 2009). Locations and ownership information for each of these SDs and CSOs, and associated drainage basins, is shown in Figure 2. Drainage basins and outfalls are identified with a numbering system created during development of the *Initial Source Evaluation and Data Gaps Memorandum* (Anchor QEA and Windward 2009). Bridges and port aprons are identified with a number that corresponds to the closest SD[6]. Two of the outfalls (at S Hinds Street and S Lander Street) are shared discharge points for separated SD basins and CSOs. These outfalls are referred to as CSO/SD outfalls. Solids loading for current conditions for the stormwater and CSO components of the discharge are discussed in detail in Sections 7.2.1.1 and 7.2.1.2, respectively, of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012).

The source control strategy for the EW, including a summary of ongoing and future source control activities and programs, is summarized in Section 2.12 of the FS. For modeling purposes, future source control conditions solids load from EW laterals (SDs and CSOs) were estimated based on ongoing and likely future source control measures to be implemented by the Port of Seattle (Port), City, and King County (County). Future efforts include installing storage or treatment to control CSOs and installing treatment or continued implementation of source control activities (e.g., business inspections, line cleaning, clean-outs, source tracing, etc.) to reduce pollutant contributions from SDs in the EW. Where needed, the type and efficiency of treatment assumed for the different SDs and CSOs is dependent on permitting requirements, likely treatment technologies, the size of the basin, and the type of basin (e.g., bridge, port apron, etc.). Therefore, treatment option assumptions are not the same for all EW lateral sources.

The upstream inputs to the EW, which are from the Green River and the LDW, were not tracked within the PTM and, therefore, were not varied as part of this analysis. However,

[6] The apron and bridge loads were input at the closest SD and were not tracked separately; however, their future input conditions were calculated separately.

the influence of uncertainty in upstream inputs on the EW were evaluated as part of the sensitivity analysis in Appendix J of the FS.

3.1 Storm Drains

Anticipated future changes to City and Port SDs for purposes of PTM evaluation are discussed below. No changes are assumed for this analysis for private SDs, SW Florida Street SDs, or U.S. Coast Guard SDs (see Figure 2).

3.1.1 City of Seattle

The City is currently not required to treat stormwater discharges from its municipal separated storm system. Instead, the Phase 1 Municipal Stormwater permit requires the City to develop and implement a stormwater management program to reduce the discharge of pollutants from the City drainage system. The program includes a number of elements to reduce pollution such as controlling runoff from new and redevelopment projects, requiring source controls for all existing development, and identifying and eliminating illicit connections and discharges to the City's drainage system. The City is currently in compliance with its permit. The City has also implemented an aggressive source control program in the EW. Therefore, for this analysis, it is assumed that solids loading from City SDs will not change in the future (see Appendix F of the STER; Anchor QEA and Coast & Harbor Engineering 2012). Instead, for future scenarios, it is assumed that the chemical concentrations of the solids in the discharge from City SDs will decline over time as a result of the City's ongoing source control program (see Table 1 for specific City SDs this applies to). Changes in stormwater solids chemistry are estimated using the data collected to date and considering that specific sources found to date will be controlled (see Appendix J of the FS for more detailed discussion on chemistry assignments). This updated chemistry will be applied to the following City SD outfalls as part of the recontamination evaluation.

- S Hinds St SD
- S Lander St SD
- SW Florida St SD (B-21)
- SW Spokane St PS 73 EOF/SD (B-5)
- SW Spokane St SD (B-4)
- S Spokane St SD (B-36).

- S Massachusetts St SD (B-25)
- BR-4 and BR-34

Chemistry assumptions applied to modeling efforts are provided in Section 5 of the FS.

3.1.2 Port of Seattle

The Port leases nearshore properties to private terminal operators. The terminal operators are required to operate the facilities in accordance with the NPDES Industrial Stormwater General Permit (ISGP), which is administered by the Washington State Department of Ecology. The ISGP includes discharge water quality benchmarks that are reported to the state on a quarterly basis by the submittal of Discharge Monitoring Reports (DMRs). If benchmarks are exceeded, the ISGP prescribes the implementation of operational, structural, and treatment best management practices (BMPs). Port properties that are not leased to private operators are covered under the Port's Municipal Stormwater Permit, with the exception of the Port's maintenance facility which is an industrial operation covered by an ISGP.

Port terminal tenants discharging to the EW under the ISGP are required to comply with all Corrective Actions (Level 1, 2, and 3), including the construction and operation of Level 3 treatment BMPs. The assumed design criterion, for Level 3 treatment BMPs, is to treat 91% of the stormwater flows from the entire property or portion of the property where monitoring data trigger a Level 3 Corrective Action. Based on the implementation of treatment BMPs at similar terminal operations in the area, stormwater treatment is likely required, to some extent, at all of these facilities to meet the ISGP benchmarks. Therefore, it is assumed for this analysis that the terminal operations discharging to the EW will install and operate stormwater treatment in the future to comply with the ISGP requirements. Table 1 presents the storm drain areas where stormwater flows are assumed to require treatment in the future.

For future source control conditions solids loads, Port basins that are assumed to have stormwater treatment installed based on ISGP conditions had adjustments made to both TSS and particle size distribution. Table 2 summarizes assumed removal efficiencies of solids by grain size (four size classes) and provides the resultant particle size distributions used to develop future source control solids loading for the base and low and high bounding runs from the current solids loading. The future conditions solids loading were calculated by applying a reduction scaling factor to current conditions solids loads. The current conditions solids loads were developed as part of the EW STE using a hydrologic model (see Appendix F of the STER; Anchor QEA and Coast & Harbor Engineering 2012). The chemical concentrations in solids are not expected to change as a result of corrective actions; however, the total contaminant mass is reduced proportional to reductions in solids loading. The method used to develop future conditions solids load for each SD is described below:

1. Removal efficiencies (Table 2) are used to calculate the total percent reduction in solids loads for Port SDs
   - The cumulative reduction factor for the base case is 83%
   - The cumulative reduction factor for the low bounding case is 91%
   - The cumulative reduction factor for the high bounding case is 74%
2. The future source control total solids load for each Port SD receiving treatment is estimated by applying the reduction factors in step 1 to the estimates of total solids load for current conditions (see Appendix F of the STER; Anchor QEA and Coast & Harbor Engineering 2012)
3. The total solids load for each SD (for future source control conditions from step 2) is parsed out over the four sediment size classes based on assumed particle size distributions following treatment (Table 2).

3.2 Combined Sewer Overflows

3.2.1 City of Seattle and King County

The City and County are required under their respective CSO NPDES permits to reduce the number of CSO discharges to, on average, one untreated event per year per outfall, which significantly reduces the total load of solids (and associated contaminants) to the EW. Table 3 identifies PTM assumptions for each CSO basin, including treatment scenarios used to develop future source control solids inputs for the base case and low and high bounding runs for EW CSOs.

The S Hinds CSO is being evaluated as part of the City's Long Term Control Plan. The City plans to install storage to control overflows from the Hinds CSO. Storage will allow flows[7] to be stored until the Elliott Bay Interceptor has capacity available to receive flows to be transported to the West Point Wastewater Treatment Plant. The Hinds CSO will, therefore, be modeled with reduced flow for future source control conditions. No changes to either chemistry or particle size distributions were assumed for the future Hinds CSO discharge.

The County will meet this requirement for the Lander and Hanford #2 CSOs by building a CSO treatment system that will remove solids and provide disinfection from the majority of the flow (King County 2012). This system will combine and treat discharges from the Hanford, Lander, Kingdome, and King CSOs. The discharge location for this combined treatment facility has not been determined at this time; for the purposes of this modeling effort, it was assumed to be the current discharge location for the Hanford #2 CSO. In addition to this combined treated discharge through the Hanford #2 outfall, one untreated discharge, on average, per year could occur through the Lander and Hanford #2 outfalls. Therefore, the PTM will include both treated and untreated discharges for these CSOs for future source control conditions. Additional information on how the removal efficiencies and particle size distributions were developed for the PTM for County CSOs is provided in Attachment 1 to this document.

3.3 Comparison of Current and Future (Source Control) East Waterway Lateral Solids Inputs

The future solids loading for all modeled basins and outfalls identified in Figure 2 were calculated based on the methodology discussed in Sections 3.1 and 3.2. The total solids loading for current and future conditions for each modeled outfall shown in Figure 2 are summarized in Table 4. Table 4 also includes the reductions in loading from current to future conditions for each modeled outfall. The cumulative reduction in solids loading from current conditions for all EW lateral sources is 34% for the base case, 51% for the low bounding run, and 23% for the high bounding run.

[7] Storage is designed such that only one discharge event on average per year would occur, because very large storm events can still overwhelm the system.

4 PARTICLE TRACKING MODEL RESULTS

The PTM was used to evaluate initial deposition of solids from identified EW lateral sources for both current and future conditions. This section focuses on future conditions because the current conditions are presented in the EW SRI (Windward and Anchor QEA 2014) and EW STER (Anchor QEA and Coast & Harbor Engineering 2012). As with the current condition model simulations, three future condition cases were run: a base case representing the best estimate and a low and high bounding run to capture the uncertainty in this estimate. The low bounding run for future conditions represents the highest anticipated removal of solids (the smallest solids load to the EW for future conditions), and the high bounding run represents the lowest anticipated removal of solids (the largest solids load to the EW for future conditions). Table 5 provides a summary of the EW lateral total solids input to the PTM and the total solids deposited in the EW for all current and future condition PTM simulations. This information will be used for evaluation of site trends over time following remediation and potential for recontamination in the EW FS due to sediment loads from identified lateral sources within the EW (see Section 5 and Appendix J). In general, results of the PTM suggest that between 70% and 75% of the solids from EW lateral sources deposits in the EW for current conditions, and between 67% and 71% deposits for future conditions. This reduction in lateral solids depositing in the EW is due to the finer-skewed particle size distribution of the future conditions as a result of stormwater and CSO treatment resulting in lower settling velocities and more particle transport out of the EW.

Figures 3, 4, and 5 show the initial deposition in kg over the simulation time period for the current conditions base case, low bounding, and high bounding runs, respectively. Figures 6, 7, and 8 show the initial deposition in kg per cell over the simulation time period for the future source control base case, low bounding, and high bounding runs, respectively.

PTM output for current and future (source control) solids loading conditions was also processed to develop maps of predicted average annual deposition rates from EW lateral sources within the EW. The annual deposition rates were calculated from the initial mass deposition raster maps (kg/simulation period) at the same resolution (50 feet by 50 feet) using the following steps:

1. Extrapolate the initial mass deposited over the simulation period (28 days) out to mass deposited over 1 year (365 days)[8]
2. Convert mass in kg to volume in cubic meters (m^3) using an assumed density[9] of 1.5 g/cm^3
3. Covert volume in m^3 to thickness (cm) in raster cell by dividing the volume by the surface area of the raster cell[10]

Figures 9, 10, and 11 provide maps of deposition rates (in cm/year) estimated from results of the initial PTM for current solids loading (see Section 7 of the EW STER; Anchor QEA and Coast & Harbor Engineering 2012) for the base case, low bounding, and high bounding runs, respectively. Figures 12, 13, and 14 provide maps of annual deposition rates for future source control conditions loading for base case, low bounding, and high bounding runs, respectively. Annual deposition rates and patterns shown on Figures 12 through 14 represent "worst case" deposition for surface concentrations due ignoring the influence of resuspension and spreading due to propwash. Resuspension and lateral transport from propwash (i.e., dispersion) will tend to distribute sediments more widely than shown on Figures 12 through 14. In areas near outfalls, dispersion will tend to reduce the contribution of lateral loads to the localized area and, therefore, reduce concentrations (because some laterals move farther from outfalls). Farther from outfalls, dispersion will tend to increase contribution of lateral loads and, therefore, could increase concentrations. The net impact of dispersion on the predicted RAL exceedance area (e.g., see Figure 9-7 of the FS) will depend on location-specific conditions, but is more likely to result in a net reduction in predicted exceedance areas.

[8] This was done using a scaler multiplication factor of 28/365 = 13.05. The average yearly deposition pattern is assumed to be the same as the 2-month pattern and the pattern does not change over different hydrographic years.
[9] The density of sediment used in this calculation was taken from measured densities of site-specific SEDflume cores (see Section 6 of the EW STER; Anchor QEA and Coast & Harbor Engineering 2012).
[10] The surface area of each 50-foot by 50-foot raster cell is approximately 232.3 square meters.

5 UNCERTAINTY DISCUSSION

The PTM methods and associated assumptions result in some uncertainties in final amount and disposition of particles. The sources of uncertainty are described below. Some inherent randomness exists within the model related to the "random walk" in the particle paths that exists within the model itself. The randomness was shown to be insignificant with respect to the initial deposition location and amount in areas where there is relatively high deposition as part of the initial modeling effort (Section 7 of the STER; Anchor QEA and Coast & Harbor Engineering 2012). Since the purpose of the PTM is to identify areas where mass contribution from lateral sources may be significant enough to present recontamination potential, the uncertainty in estimates within low deposition areas is not a serious concern for this application.

The model also does not account for the initial momentum of particles as they enter the system; this could have an influence on their final deposition location, the effect being similar to spreading the PTM discharge location along the plume trajectory. However, the scale of the hydrodynamic model (which drives the PTM simulation) is not appropriate for resolving flow fields from individual outfalls. In addition, resuspension and redeposition of sediments by ship operations is not included in the PTM simulations, which plays a larger role in ultimate disposition of particles in the EW. These last two uncertainties would further spread the depositional pattern and reduce the concentrations of contaminants near outfalls, where marginal exceedances of the RALs are more likely. A wider distribution of this mass will not significantly change the spatially-weighted average concentration (SWAC) estimates because the deposited sediment largely remains near the surface. Therefore, the exclusion of initial particle velocity and propwash effects results in a conservative estimate of recontamination potential but has little effect on future SWAC estimates (see Appendix J of the FS).

Additional uncertainties exist within the lateral source input data assumptions developed for the PTM, including removal efficiencies for future treatment options, particle size distributions, stormwater and CSO flows, and TSS and chemistry concentrations. These uncertainties have been integrated (to the extent practical) into the STE through the development of lower- and upper-bound simulations, which provide a range of model results based on variations in the input data.

Uncertainties may also arise from the hydrodynamic model due to limitations in grid resolution (both horizontally and vertically; see Section 4 of the EW STER; Anchor QEA and Coast & Harbor Engineering 2012).

As discussed, shorter-term simulations were performed to provide data that can be used to evaluate long-term conditions. Therefore, there is some uncertainty in the predictions of long-term deposition patterns due to this extrapolation. These simulations involved using a representative tidal condition and temporally constant mean annual average riverine inflow and sediment source input rates. This information, while not representative of any particular storm event, provides average deposition rates and patterns that can be utilized to evaluate recontamination potential from lateral sources over the long term.

6 REFERENCES

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TABLES

Table 1
Future Conditions for East Waterway Lateral Sources

Modeled Outfall	Untreated Basin that Discharges through Modeled Outfall[a]	Treated Basin that Discharges through Modeled Outfall[a]	Source Control Measure Solids		Source Control Measure Chemistry
			Particle Size Distribution	Annual Flow Volume	
1	A1	B1	--	--	--
2		BR2	--	--	--
4		BR4 + B4 (SW Spokane St SD)	--	--	SCP
5		BR5 + B5 (SW Spokane St EOF/SD)	--	--	SCP
6	A6	A6	--	--	--
7		B7	ISGP	--	--
10	A10	B10	ISGP	--	--
11	A11	B11	ISGP	--	--
12	A12	B12	ISGP	--	--
13	A13	B13	ISGP	--	--
14	A14	B14	ISGP	--	--
16	A16	B16	ISGP	--	--
17	A17	B17	ISGP	--	--
18	A17	B18	ISGP	--	--
19	A19	B19	ISGP	--	--
21		B21, SW Florida St SD	--	--	SCP
22	A22	B22	ISGP	--	--
23	A23	B23	ISGP	--	--
24	A24	B24	ISGP	--	--
25		B25, S Massachusetts St SD	--	--	SCP
26	A26	B26	ISGP	--	--
27	A27	B27	ISGP	--	--
28	A28	B28	ISGP	--	--
29	A29	B29	ISGP	--	--
30	A30	B30 + BR27	ISGP	--	--
31	A31	B31	ISGP	--	--
32	A32	B32	ISGP	--	--
33	A33	B33	ISGP	--	--
34	B34		--	--	--
36		S Spokane St SD	--	--	SCP
37	B37		--	--	--
39	BR39		--	--	--
39		B39	ISGP	--	--
40	B40		--	--	--
41	B41		--	--	--
42	B42		--	--	--
43	B43		--	--	--
Hinds_Storm		S Hinds St SD	--	--	SCP
Lander_Storm		S Lander St SD	--	--	SCP
Hanford		Hanford CSO	CSO treatment	--	--
Hinds		Hinds CSO	--	CSO storage	--
Lander		Lander CSO	CSO treatment	--	--

Notes:
a. See Figure 2, map of drainage basins and modeled outfalls.
Basin naming "A" refers to pier Apron locations, "B" refers to drainage Basins, and "BR" refers to Bridge locations.
"--" designates no change from current conditions.
SCP: A reduction in chemical concentrations is expected in the future as a result of the City of Seattle's ongoing source control program.
ISGP: Changes in particle size distribution and total solids loading (from current conditions) because the site will have reached Level 3 corrective action and is required under ISGP to install stormwater treatment best management practices. The solids chemistry is not expected to change as a result of corrective actions. The particles that do not get removed by stormwater facilities typically have the same concentration as prior to filtering.
CSO storage: Annual discharge volume is reduced because Seattle Public Utilities plans to install a storage tank to reduce the number of CSO discharges to the East Waterway to one uncontrolled event (on average) per year as required under the CSO National Pollutant Discharge Elimination System permit.
CSO treatment: Changes for particle size distribution and reduction in solids because King County plans to install a CSO treatment system to reduce the number of untreated CSO events to one uncontrolled event (on average) per year. Treatment can also reduce chemistry, but none was assumed for this evaluation.

CSO – combined sewer overflow
EOF – emergency overflow
ISGP – industrial stormwater general permit
SCP – source control program
SD – storm drain

Table 2
Assumed Future Conditions for Treated Port Storm Drains
(Presented as a Percent Reduction from Current Conditions)

Particle Size Class	Treated Flow (91% of total)			Untreated Flow (9% of total)
	Base Case Median TSS (43 mg/L)	Low Bounding Case 25th Percentile TSS (20 mg/L)	High Bounding Case 75th Percentile TSS (60 mg/L)	For All Cases
Removal Efficiencies				
< 5 µm (1A)	70%	80%	60%	0%
20 µm to 129 µm (1B)	80%	90%	70%	0%
130 µm to 539 µm (2)	80%	90%	70%	0%
> 540 µm (3)	90%	95%	80%	0%
Particle Size Distributions				
< 5 µm (1A)	26%	32%	22%	15%
20 µm to 129 µm (1B)	26%	24%	25%	23%
130 µm to 539 µm (2)	29%	27%	28%	26%
> 540 µm (3)	20%	18%	25%	35%

Notes:

Only 91% of total flow is treated; 9% of total flows retain current solids conditions.

µm – micrometer

mg/L – milligram per liter

TSS – total suspended solids

Table 3
Future Conditions for East Waterway Combined Sewer Outfalls

Outfall	Treatment	Flow Volume (million gallons/year)			TSS (mg/L)	Future Removal Efficiency (%)				Future Particle Size Distribution (%)[e]			
		Current	Future	Note		Class 1A	Class 1B	Class 2	Class 3	Class 1A	Class 1B	Class 2	Class 3
Base Case Run													
Hanford #2	Untreated (volume reduced through treatment)	74.3	1.0	a	86	--	--	--	--	42	41	17	0
Lander	Untreated (volume reduced through treatment)	39.8	0.6	b	86	--	--	--	--	42	41	17	0
Hanford #2	Treated Flow (70% removal efficiency)	0	164	c	25.8	70	100	100	100	100	0	0	0
Hinds	Untreated (volume reduced through storage)	1.0	0.6	d	86	--	--	--	--	42	41	17	0
Lower Bounding Run													
Hanford #2	Untreated (volume reduced through treatment)	74.3	1.0	a	65.3	--	--	--	--	42	41	17	0
Lander	Untreated (volume reduced through treatment)	39.8	0.6	b	65.3	--	--	--	--	42	41	17	0
Hanford #2	Treated Flow (90% removal efficiency)	0	164	c	6.53	90	100	100	100	100	0	0	0
Hinds	Untreated (Volume Reduced through Storage)	1.0	0.6	d	65.3	--	--	--	--	42	41	17	0
Upper Bounding Run													
Hanford #2	Untreated (volume reduced through treatment)	74.3	1.0	a	106	--	--	--	--	42	41	17	0
Lander	Untreated (volume reduced through treatment)	39.8	0.6	b	106	--	--	--	--	42	41	17	0
Hanford #2	Treated Flow (50% removal efficiency)	0	164	c	53	70	85	95	100	60	30	10	0
Hinds	Untreated (volume reduced through storage)	1.0	0.6	d	106	--	--	--	--	42	41	17	0

Notes:

a. This volume represents one untreated CSO event per year (on average) at Hanford #2, which meets Washington State Law. The remainder of the flow will be treated.

b. This volume represents one untreated CSO event per year (on average) at Lander, which meets Washington State Law. The remainder of the flow will be treated and discharged through Hanford #2 outfall.

c. A treatment facility will be constructed to treat flow from four CSOs (Hanford #2 and Lander [within the EW], and Kingdome and King [north of the EW]). The location of the discharge has yet to be determined by King County, but is assumed to be Hanford #2 outfall for this evaluation.

d. A storage tank will be constructed to store flow from Hinds CSO so that there is only one CSO discharge per year (on average), which meets Washington State Law.

e. Projections of particle size distribution of less then 0.01% are presented as 0; particle size distribution classes are the same as shown in Table 2.

µm – micrometer
mg/L – milligram per liter
EW - East Waterway
TSS – total suspended solids

Particle Size Classes

Class 1A: < 5 µm
Class 1B: 20 µm to 129 µm
Class 2: 130 µm to 539 µm
Class 3: > 540 µm

Table 4
Comparison of Predicted Current and Future East Waterway Lateral Solids Inputs

				Annual Average Total Solids Load (kg)								
Modeled Outfall	Type	Owner	Drainage Basins[a]	Base Case Current (kg)	Base Case Future Source Control (kg)	% Reduction (% by mass)	Lower Bound Current (kg)	Lower Bound Future Source Control (kg)	% Reduction (% by mass)	Upper Bound Current (kg)	Upper Bound Future Source Control (kg)	% Reduction (% by mass)
Sum of all East Waterway Lateral Sources				**113,093**	**74,605**	**34%**	**63,874**	**31,017**	**51%**	**150,961**	**116,025**	**23%**
1	SD	POS	A1 + B1	171	51	70%	79	18	77%	239	94	61%
2	SD	POS	BR2	29	29	none	13	13	none	40	40	none
4	SD	SPU	BR4 + B4 (SW Spokane St SD)	1,468	1,468	none	689	689	none	2,079	2,079	none
5	SD	SPU	BR5 + B5 (SW Spokane St EOF/SD)	643	643	none	305	305	none	832	832	none
6	SD	Private	A6	590	590	none	271	271	none	932	932	none
7	SD	POS	A6 + B7	1,632	571	65%	761	217	71%	2,284	1,005	56%
10	SD	POS	A10 + B10	1,032	480	54%	480	198	59%	1,440	776	46%
11	SD	POS	A11 + B11	5,223	1,544	70%	2,429	549	77%	7,287	2,868	61%
12	SD	POS	A11 + B12	923	424	54%	429	174	59%	1,288	688	47%
13	SD	POS	A 13 + B13	725	250	66%	337	95	72%	1,012	441	56%
14	SD	POS	A13 + B14	276	161	42%	128	69	46%	386	247	36%
16	SD	POS	A16 + B16	550	206	63%	255	83	67%	767	362	53%
17	SD	POS	A 17 + B17	306	142	53%	142	59	59%	427	231	46%
18	SD	POS	A18 + B18	933	368	61%	434	145	67%	1,303	623	52%
19	SD	POS	A19 + B19	752	367	51%	349	153	56%	1,049	586	44%
21	SD	SPU	B21, SW Florida St SD	1,408	1,408	none	655	655	none	1,965	1,965	none
22	SD	POS	A22 + B22	1,519	603	60%	706	238	66%	2,119	1,018	52%
23	SD	POS	A23 + B23	1,410	573	59%	655	228	65%	1,967	962	51%
24	SD	POS	A 24 + B24	1,209	532	56%	562	216	62%	1,687	874	48%
25	SD	SPU	B25, S Massachusetts St SD	657	657	none	328	328	none	987	987	none
26	SD	POS	A 26 + B26	1,519	495	67%	706	183	74%	2,120	889	58%
27	SD	POS	A27 + B27	981	419	57%	456	169	63%	1,368	694	49%
28	SD	POS	A28 + B28	552	278	50%	257	117	55%	771	441	43%
29	SD	POS	A29 + B29	1,073	405	62%	498	157	68%	1,497	694	54%
30	SD	POS	A 30 + B30 + BR27	866	355	59%	403	142	65%	1,210	596	51%
31	SD	POS	A31 + B31	1,147	397	65%	533	150	72%	1,601	700	56%
32	SD	POS	A32 + B32	491	207	58%	228	83	64%	685	343	50%
33	SD	POS	A33 + B33	1,549	625	60%	720	248	66%	2,162	1,051	51%
34	SD	POS	B34	2,457	726	70%	1,129	255	77%	3,884	636	84%
36	SD	SPU	S Spokane St SD	1,061	1,061	none	502	502	none	1,399	1,399	none
37	SD	POS	B37	689	204	70%	320	72	77%	962	378	61%
39	SD	SPU	BR39	234	234	none	107	107	none	369	369	none
39	SD	POS	B39	225	67	70%	105	24	77%	314	124	61%
40	SD	Private	B40	449	449	none	239	239	none	650	650	none
41	SD	Private	B41	857	857	none	394	394	none	1,354	1,354	none
42	SD	Private	B42	86	86	none	39	39	none	136	136	none
43	SD	Private	B43	1,071	1,071	none	492	492	none	1,694	1,694	none
Hanford #2[b]	CSO	KC	Hanford CSO	24,188	16,342	32%	18,366	4,301	77%	29,813	33,304	-12%
Hinds[c,e]	CSO	SPU	Hinds CSO	326	207	36%	247	207	16%	401	207	48%
Lander[d]	CSO	KC	Lander CSO	12,957	195	98%	9,838	148	98%	15,970	241	98%
Hinds_Storm	SD	SPU	S Hinds St SD	6,920	6,920	none	3,215	3,215	none	10,231	10,231	none
Lander_Storm	SD	KC	S Lander St SD	31,940	31,940	none	15,070	15,070	none	42,279	42,279	none

Table 4
Comparison of Predicted Current and Future East Waterway Lateral Solids Inputs

Notes:
a. See Figure 2 for a map of basins and outfall locations. See Table 1 for a list of treatment options for each basin assigned to a modeled outfall.
b. Future conditions for Hanford #2 include re-routing of treated discharges from Lander, Kingdome, and King CSOs through the Hanford #2 discharge location.
c. The Future Source Control reduction in solids load for Hinds CSO is due to reduction in flow (storage).
d. The Future Source Control reduction in solids load for Lander CSO is due to treated flows being discharged through Hanford #2 outfall.
e. This flow represents one untreated CSO discharge into the EW per year for the Hanford, Lander, and Hinds CSOs, as allowed by the National Pollutant Discharge Elimination System.
Basin naming "A" refers to pier Apron locations, "B" refers to drainage Basins, and "BR" refers to Bridge locations.
CSO – combined sewer overflow
EOF – emergency overflow
EW - East Waterway
KC – King County
kg – kilogram
POS – Port of Seattle
SD – storm drain
SPU – Seattle Public Utilities

Table 5
Summary of Particle Tracking Model Results for East Waterway Lateral Loads

Model Run	Total Mass (kg) Input into Model over Simulation Period[1]	Total Mass Deposited in EW at End of Simulation[2]		Total Mass in Suspension in EW at End of Simulation[3]		Total Mass that has Left the EW at End of Simulation	
		kg	% of total input	kg	% of total input	kg	% of total input
Base Case, Current	8,626	6,490	75%	411	5%	1,725	20%
Lower Bound, Current	4,855	3,487	72%	254	5%	1,114	23%
Upper Bound, Current	11,560	8,751	76%	538	5%	2,271	20%
Base Case, Future	5,651	3,798	67%	323	6%	1,530	27%
Lower Bound, Future	2,313	1,655	72%	130	6%	528	23%
Upper Bound, Future	8,803	6,193	70%	452	5%	2,158	25%

Notes:

1. The simulation period included 28 days, with 14 additional days (spin down) with loading sources set to 0 to allow finer particles released into the model to settle.
2. This value represents initial deposition within the EW and does not include resuspension due to propeller wash or other vessel operations.
3. This value represents particles that were still in suspension above the bed in the model after the total 42 days of simulation time (including the 14 days of spin-down time).

Summary of PTM Results - Estimated Annual EW Lateral Loads

Model Run	Annual[1] Input (kg)	Total Mass Deposited in EW Annually[1] (kg)	Mass Deposited in EW from CSOs (kg)	Mass Deposited in EW from SDs (kg)
Base Case, Current	112,483	84,630	21,819	62,811
Lower Bound, Current	63,309	45,475	16,372	29,103
Upper Bound, Current	150,742	114,117	26,659	87,457
Base Case, Future	73,689	49,527	3,153	46,374
Lower Bound, Future	30,162	21,578	1,016	20,561
Upper Bound, Future	114,791	80,760	14,528	66,231

Note:

1. The simulation period included 28 days. To estimate annual loads, the simulation period results were multiplied by 13.04.

Notes:

CSO – combined sewer overflow
EW – East Waterway
kg – kilogram
PTM – particle tracking model
SD – storm drain

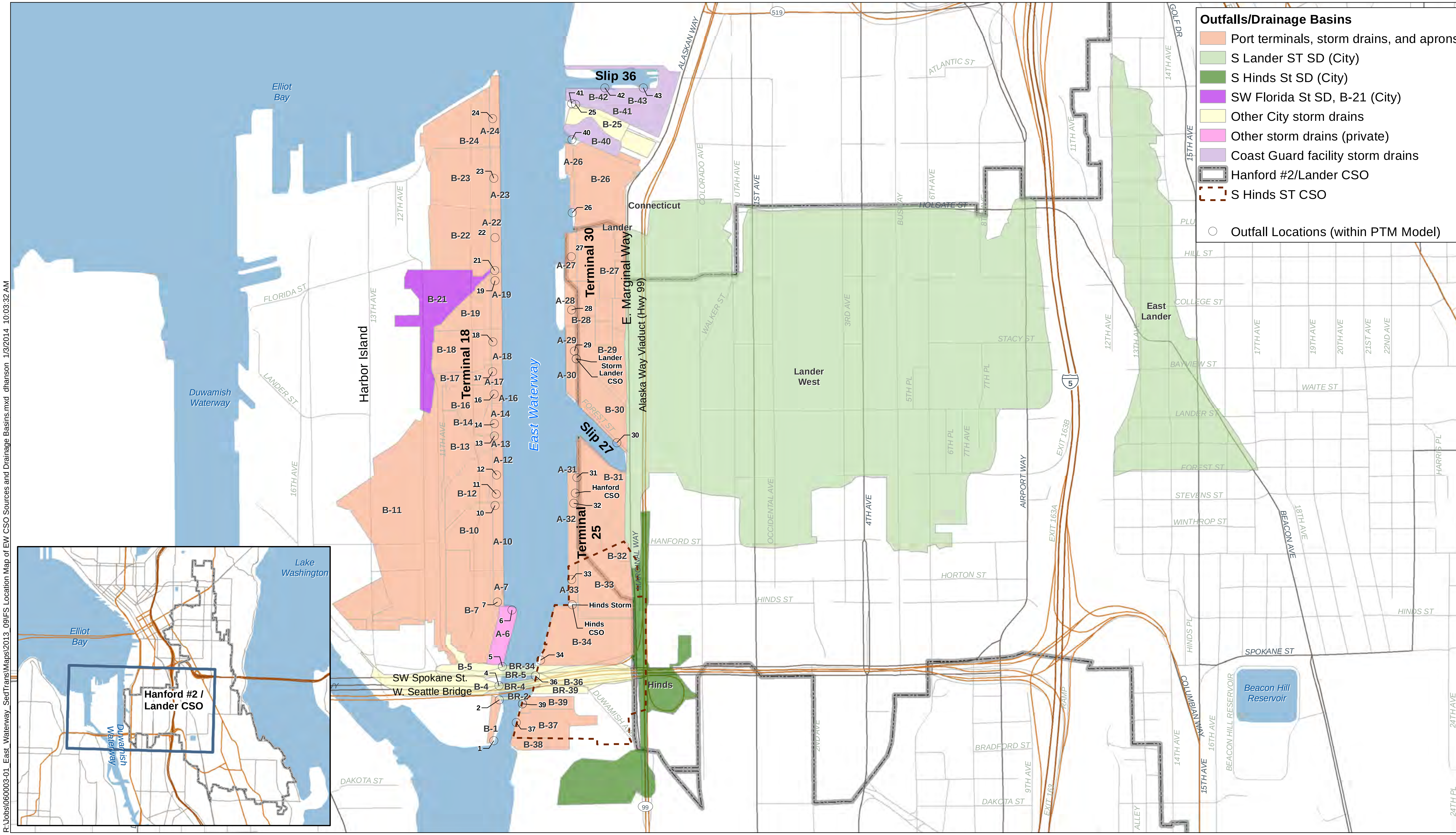
FIGURES

R:\Jobs\060003-01_East_Waterway_SedTrans\Maps\2013_08\FS Hydrodynamic Model Grid within EW.mxd epipkin 10/11/2013 3:27:42 PM

NOTE: Aerial photo is NAIP, 2011.

0 250 500 750 1,000
Scale in Feet

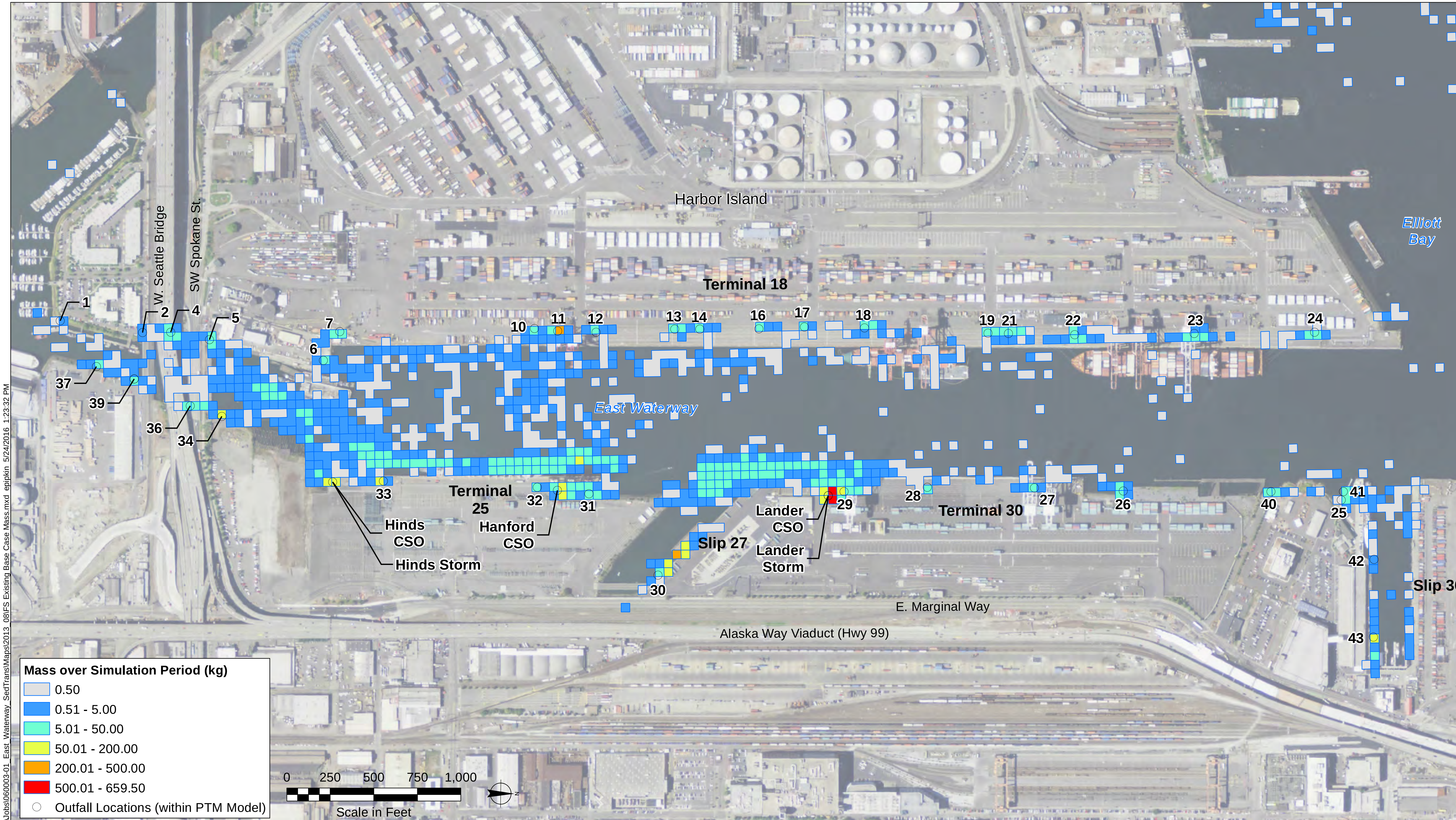
Figure 1
Hydrodynamic Model Grid within the EW
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



0 500 1,000 1,500 2,000

Scale in Feet

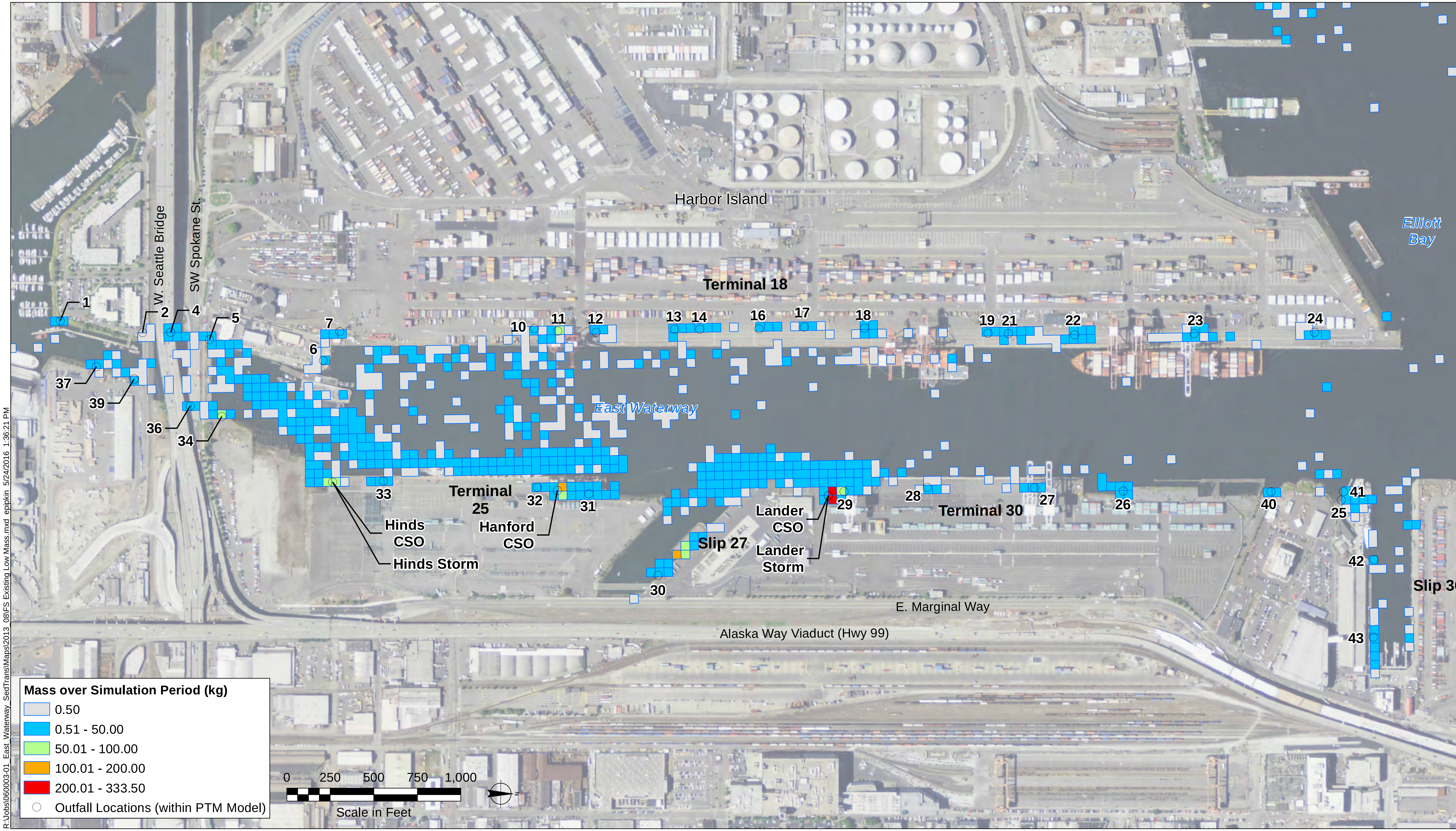
Figure 2
Location Map of EW Storm Drain and CSO Basins and Outfalls
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



R:\Jobs\060003-01_East_Waterway_SedTrans\Maps\2013_08\FS Existing Base Case Mass.mxd epipkin 5/24/2016 1:23:32 PM

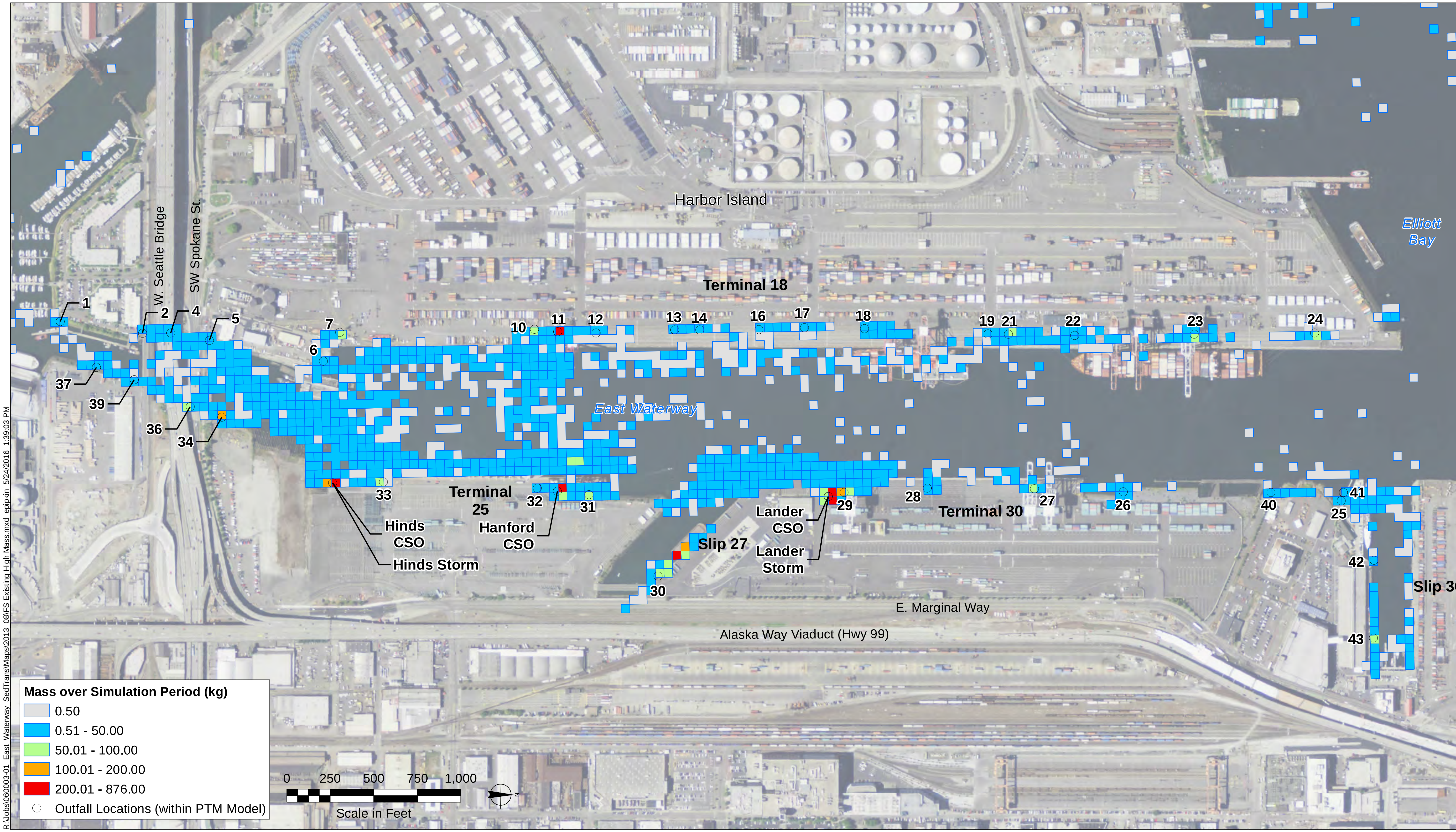
NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 3
PTM Model Simulation Existing Source Control Base Case - Mass Accumulation during Simulation Period (kg)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



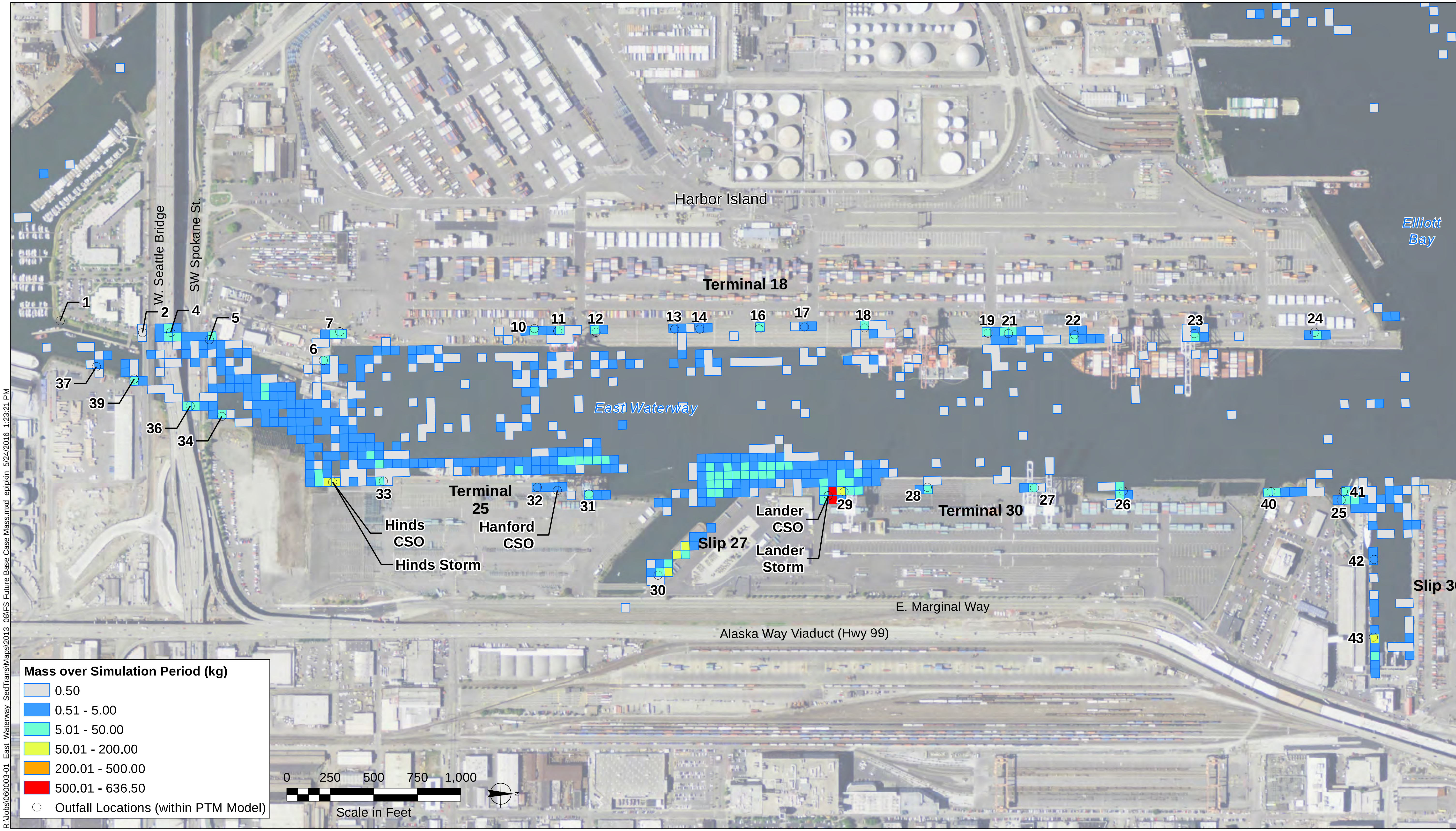
NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 4
PTM Model Simulation Existing Source Control Low Bounding Case - Mass Accumulation during Simulation Period (kg)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 5
PTM Model Simulation Existing Source Control High Bounding Case - Mass Accumulation during Simulation Period (kg)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area

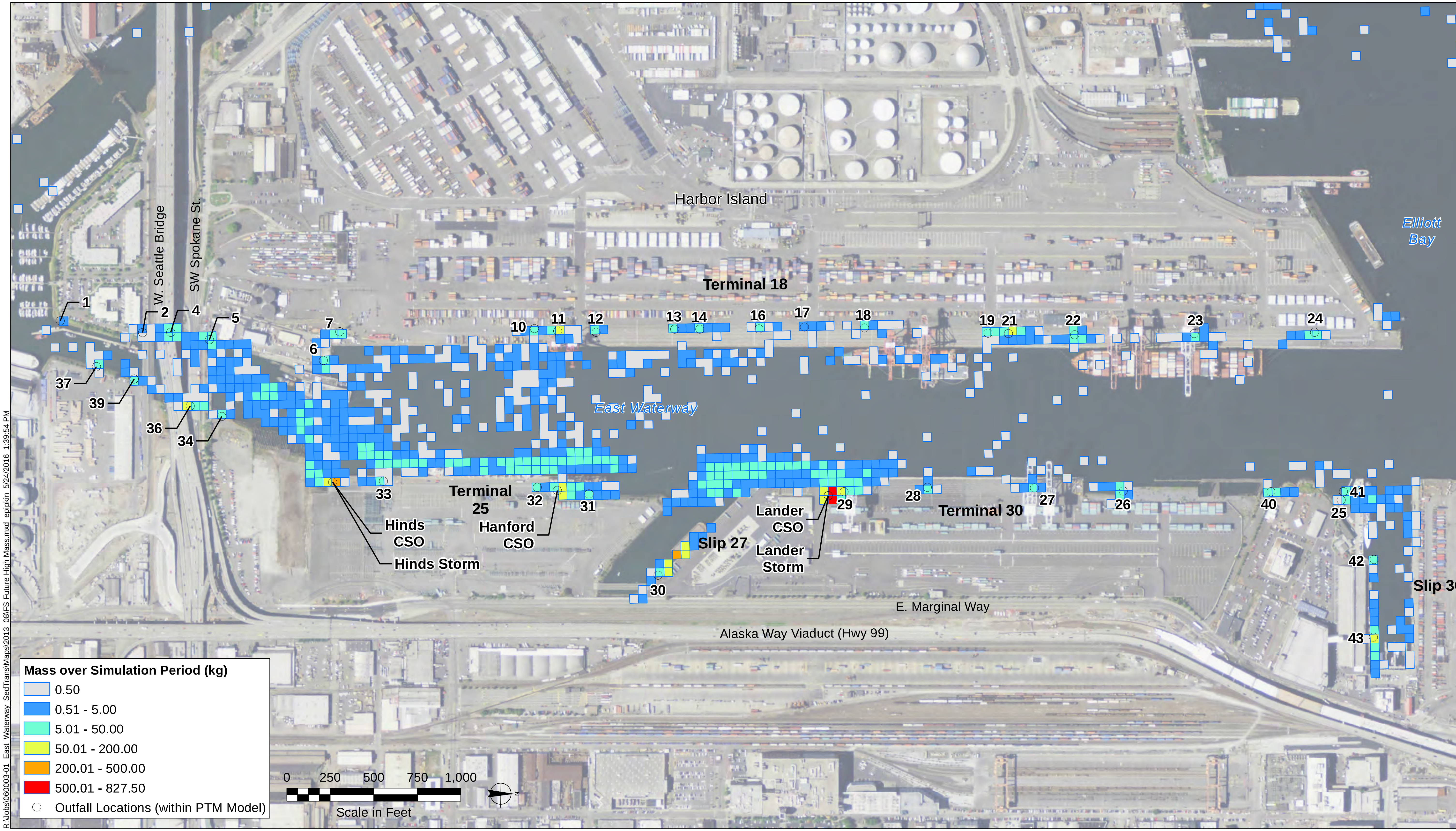


NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 6
PTM Model Simulation Future Source Control Base Case - Mass Accumulation during Simulation Period (kg)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area

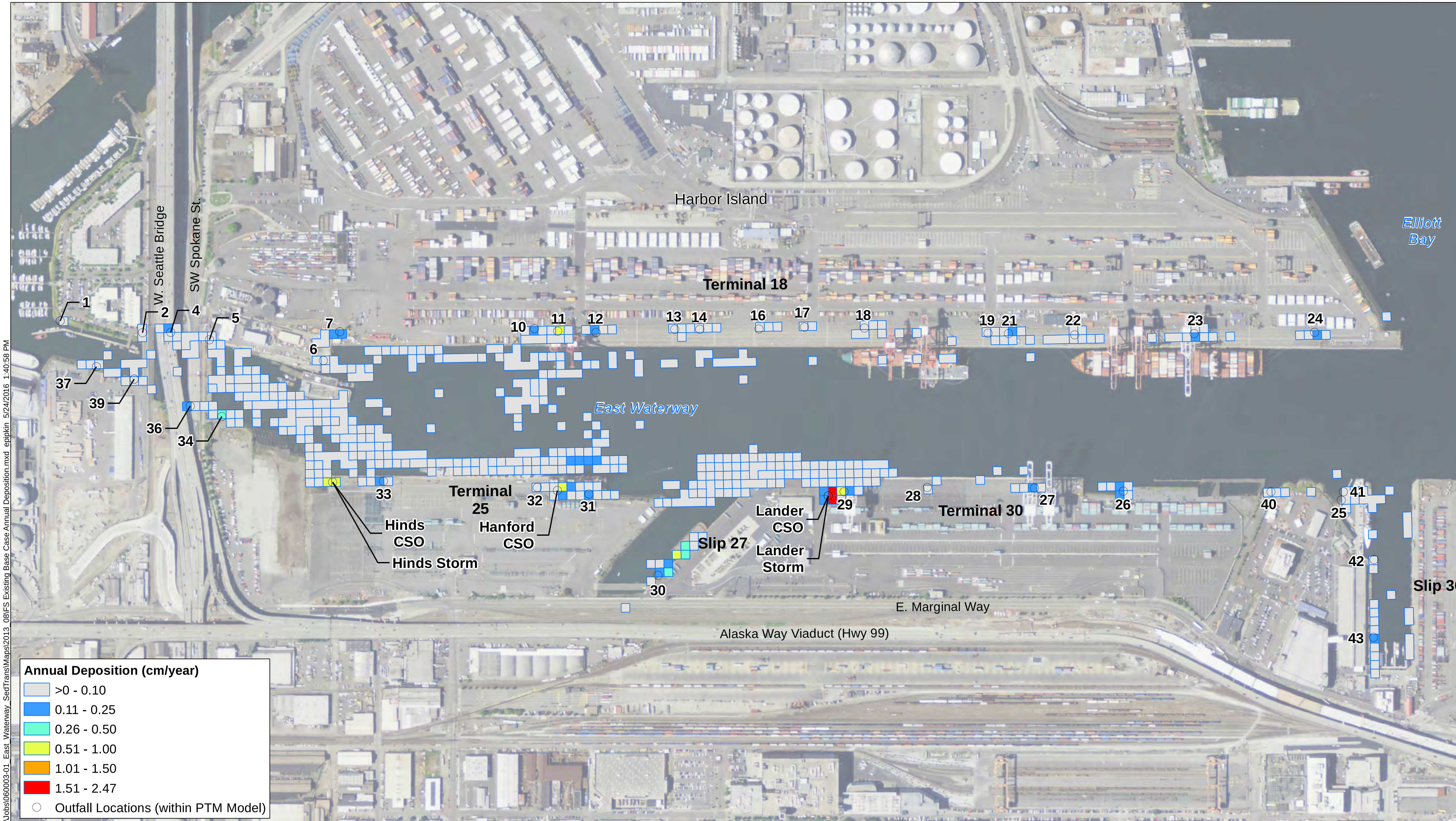
NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 7
PTM Model Simulation Future Source Control Low Bounding Case - Mass Accumulation during Simulation Period (kg)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 8
PTM Model Simulation Future Source Control High Bounding Case - Mass Accumulation during Simulation Period (kg)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



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NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

0 250 500 750 1,000

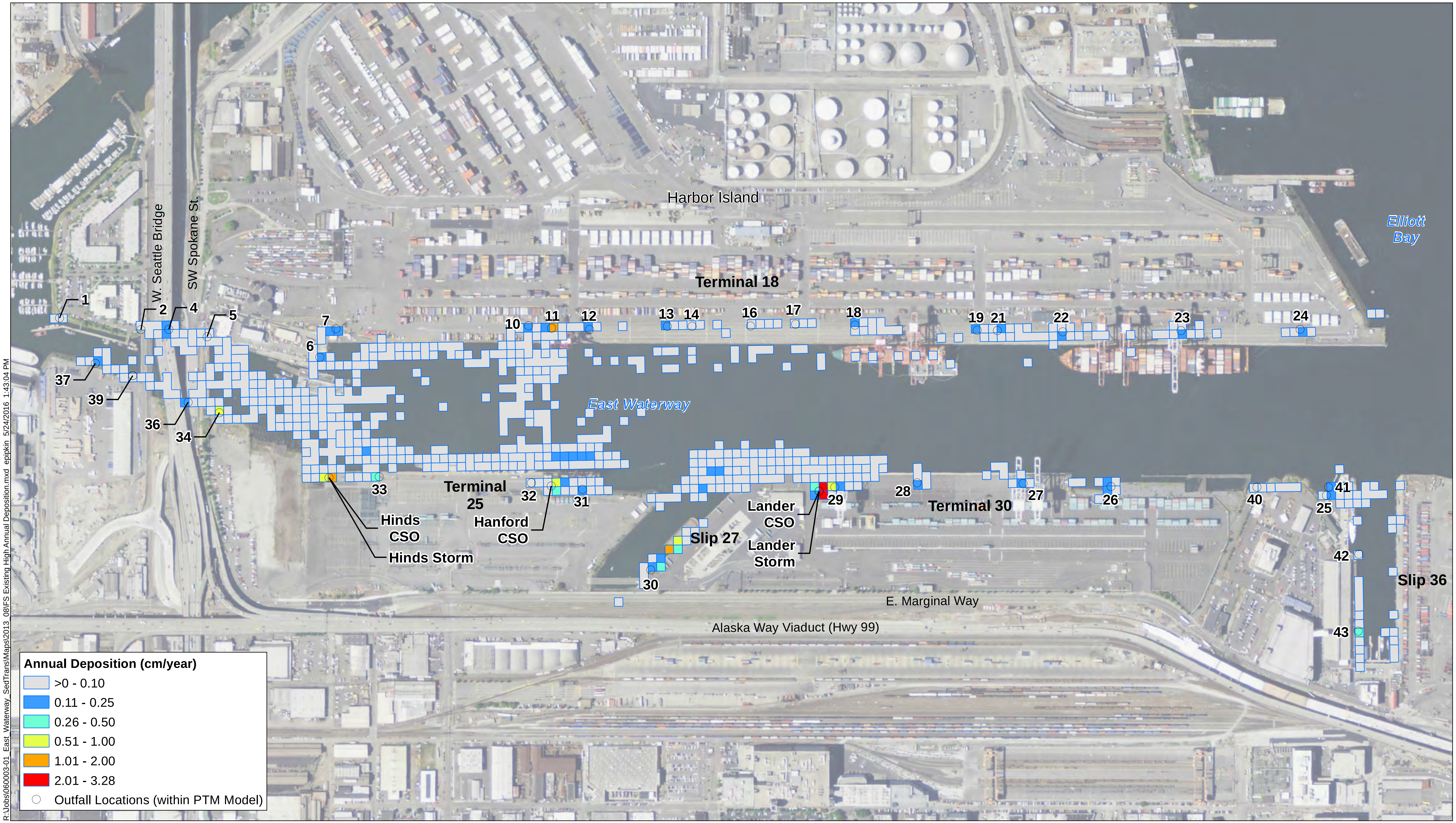
Scale in Feet

Figure 9
PTM Model Simulation Current Conditions Base Case - Annual Initial Deposition (cm/year)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area

NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

0 250 500 750 1,000
Scale in Feet

Figure 10
PTM Model Simulation Current Conditions Low Bounding Case - Annual Initial Deposition (cm/year)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



NOTES:

1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

0 250 500 750 1,000

Scale in Feet

Figure 11

PTM Model Simulation Current Conditions High Bounding Case - Annual Initial Deposition (cm/year)

Feasibility Study - Appendix B, Part 1

East Waterway Study Area

NOTES:

1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

0 250 500 750 1,000

Scale in Feet

Figure 12

PTM Model Simulation Future Source Control Base Case - Annual Initial Deposition (cm/year)

Feasibility Study - Appendix B, Part 1

East Waterway Study Area

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NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

Figure 13
PTM Model Simulation Future Source Control Low Bounding Case - Annual Initial Deposition (cm/year)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area

NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

Figure 14
PTM Model Simulation Future Source Control High Bounding Case - Annual Initial Deposition (cm/year)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area

ATTACHMENT 1

King County
Department of Natural Resources and Parks
Wastewater Treatment Division
King Street Center, KSC-NR-0500
201 South Jackson Street
Seattle, WA 98104-3855

MEMO

Date: May 20, 2013

TO: Jeff Stern-Sediment Management Program Manager, Wastewater Treatment Div, DNRP
Debra Williston, Toxicology and Contaminant Assessment Grp, Water and Land Resources Div, DNRP

Cc: Kathy Ketteridge, Anchor QEA

FM: Bruce Nairn, Modeling and GIS, Wastewater Treatment Div, DNRP

RE: **Methodology to determine grain size following CSO treatment for use in East Waterway Feasibility Study modeling**.

This Memo describes the approach used to estimate the grain size distributions from combined sewer overflow (CSO) discharges following CSO treatment for Hanford #2 and Lander CSOs that discharge to East Waterway (EW). The grain size distributions are applied to the size distributions used for the Particle Tracking Model (PTM) used in the EW Feasibility Study.

For the purposes of the EW Feasibility Study, the particulate size of solids in the CSO discharge is represented by a fixed number of size classes described by a characteristic settling velocity. The sediment represented by each settling velocity is termed a sediment class. Distributions of particles in untreated CSO discharges were estimated based on past sampling of CSO effluent in several King County studies. The data were collected from four County CSO systems, and distributions were determined as a cumulative percentage of the total mass of solids (Battelle 2006). The PTM grain size distributions used for the current CSO conditions (i.e., no treatment) were presented and discussed in the EW Sediment Transport Evaluation Report (Anchor QEA and Coast & Harbor Engineering 2012).

Preliminary screening of potential CSO treatment technologies suggests that the most likely type of treatment technology is a variation of a sedimentation process. These technologies range from primary sedimentation to high-rate sedimentation. For this modeling assessment, three levels of treatment effectiveness were assumed: 50%, 70%, and 90% total suspended solids (TSS) removal. Grain size distribution following CSO treatment was estimated by applying the specified removal efficiency with the characteristics of an ideal settling process to the untreated CSO grain size distribution.

To simulate removal efficiencies of the treatment technology, an idealized plug-flow reactor was assumed. In an idealized plug-flow reactor, water enters a tank and flows through it without mixing. Particles are evenly distributed in the flow as they enter the tank and those that reach the bottom before exiting are captured. The design parameter for a plug-flow reactor is the surface overflow rate (v_o). If a particle's settling velocity (w_s) is greater than the overflow rate, all particles are removed. Otherwise the removal rate is proportional to the settling velocity:

$w_s > v_o$: capture = 100 %
$w_s < v_o$: capture = 100*(w_s / v_o) %

The approach was to determine the surface overflow rate that resulted in 50%, 70%, or 90% TSS removal for the CSO settling velocity distribution. This resulted in the relative fraction of particulate mass in each size class as shown in Table 1. This particulate fraction is applied to the average CSO TSS concentration, so removal of particulates by CSO treatment results in a total fraction less than 100 percent.

Table 1. Settling Velocity Distributions by Cumulative Mass Percentage for Three CSO Treatment Efficiencies

		Fraction in Range (%)			
Sediment Class	**Settling Velocity (m/s)**	**No removal**	**50% removal**	**70% removal**	**90% removal**
3	1.18×10^{-1}	0	-	-	-
2	8.9×10^{-3}	17.0	-	-	-
1B	2.4×10^{-4}	41.0	10.0	-	-
1A	1.5×10^{-5}	42.0	40.0	30.0	10.0
	Total	**100.0**	**50.0**	**30.0**	**10.0**

No processes such as particle flocculation or disaggregation that could modify the particle settling velocity were assumed. An investigation into particle flocculation during the discharge of untreated CSO effluent into marine waters found that the particle flocculation models considered did not predict flocculation to occur (Battelle, 2006). Flocculation occurs within many treatment processes which has the potential to increase the settling velocity of the particles in the discharged effluent. As no information is available on how treatment processes might alter the settling velocity of particles in the discharged effluent, the particle settling velocities were assumed to be unaffected by the treatment process.

How well the actual treatment process will approach the theoretical removal efficiencies is currently unknown. King County did pilot a high rate sedimentation process (King County, 2010) in which total removal rates and particle size distributions were measured. Removal rates of 75% - 100% were observed over a range of operating conditions.   The pilot study did not measure settling velocity or particle density, making it impossible to relate measured particle sizes into sediment classes. Particles in sewage and CSOs are primarily organic with specific gravities much lower than sand or clay. Thus using the specific gravity of sand/clay and the particle diameters to estimate settling velocity significantly overestimates the actual settling velocity.

To model size distributions in the EW Feasibility Study, a base assumption of 70% TSS removal is recommended. King County's CSO Control Plan (2012) proposes high rate clarification to treat CSO discharges at Hanford and Lander CSOs. This type of technology should be able to obtain more than seventy percent TSS removal, making this a conservative estimate. The uncertainty in the treatment process removal rates, in addition to uncertainty in the composition of the untreated CSO particles was included in the sediment classes for the upper and lower bounding runs (Table 2). The lower bound corresponds to 90% TSS removal, while the upper bound corresponds to 50% TSS removal with a shift to more large particles released. This shift is intended to capture variations in CSO particle distributions as well as incomplete removal in the treatment process.

Table 2. Settling Velocity Distributions for Upper and Lower Bounding Runs

		Fraction in Range (%)			
Sediment Class	**Settling Velocity (m/s)**	**No removal**	**Base Assumption[1]**	**Lower Bound[2]**	**Upper Bound[3]**
3	1.18×10^{-1}	0	-	-	-
2	8.9×10^{-3}	17.0	-	-	5.0
1B	2.4×10^{-4}	41.0	-	-	15.0
1A	1.5×10^{-5}	42.0	30.0	10.0	30.0
	Total	**100.0**	**30.0**	**10.0**	**50.0**

[1] Based on 70% removal efficiency of TSS.
[2] Based on 90% removal efficiency of TSS.
[3] Based on 50% removal efficiency of TSS.

Citations

Battelle Memorial Institute. 2006. Investigation of the capabilities of the model EFDC for use in the evaluation of sediment contamination: Discharge modeling contaminated sediment cleanup decisions. Prepared for King County Department of Natural Resources and Parks.

King County Department of Natural Resources and Parks. 2010. Combined Sewer Overflow Treatment Systems Evaluation and Testing. Phase 2 Pilot Test Report. Prepared by CDM.

Anchor QEA and Coast & Harbor Engineering, 2012. Final Sediment Transport Evaluation Report (STER), East Waterway Operable Unit Supplemental Remedial Investigation/ Feasibility Study. Prepared for Port of Seattle. August.

PART 2: SCOUR DEPTH ANALYSIS MEMORANDUM

COAST & HARBOR ENGINEERING

Technical Memorandum

Port of Seattle, East Waterway Scour Analysis

1. Introduction

This technical memorandum summarizes the results of analysis conducted by Coast & Harbor Engineering (CHE) to estimate a scour depth due to propwash from vessels maneuvering in the East Waterway, Port of Seattle.

2. Methodology and Input Data

Propwash generated scour depth was computed using the modified analytical method of de Graauw and Pilarcyzk (1980) calibrated with historical bathymetric survey data in the East Waterway and data from Sedflume experiments (LDWG 2007[1], Anchor QEA and CHE 2012).

Analysis of the East Waterway historical bathymetry survey data has identified localized areas of bottom depressions that were assumed to be generated by propwash activities from various ships maneuvering in the waterway. Figure 1 shows identified depressions at Berths 1 and 2 on the northern end of Terminal 18 (T18). The bathymetric survey data in this area was used for calibration of site specific constants in the modified computation method developed by Graauw and Pilarcyzk, 1980 to account for site specific conditions within the EW. The calibrated methodology was then applied to compute potential scour depths within the East Waterway based on vessel operations identified in the EW Sediment Transport Evaluation Report (STER, Anchor QEA and Coast and Harbor Engineering, 2012).

Critical shear stress values for sediment samples taken from various locations within the East Waterway were measured as part of the sediment transport evaluation and are summarized in Section 6.1 of the STER. The critical shear stress values of eight cores from the East Waterway were depth averaged by CHE and are assumed to represent the sediment strength within each of the operational areas, which were cross-referenced with the locations of cores tested in the Sedflume experiments.

Bottom velocities and bed shear stress values, determined by a previous vessel hydrodynamic modeling study (see Section 5.2 and Appendix H of the STER, Anchor QEA and Coast and Harbor Engineering, 2012), were used as input into the scour model.

[1] Calibration was also based on the data presented in Appendix G of this report.

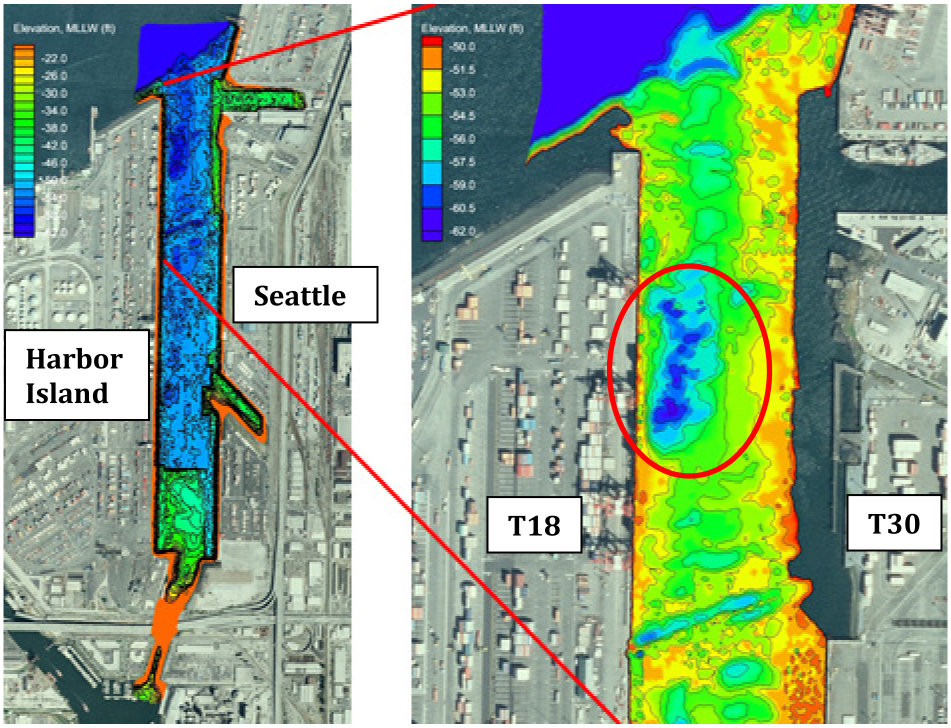

Figure 1. Bathymetric survey of East Waterway at Port of Seattle. Deep blue colors indicate deeper depths. Depressions at Berths 1 and 2 (circled in red).

Scour depth was calculated for each delineated operational area shown in Figure 2. The boundaries of the areas and corresponding maneuvering operations were coordinated by the Project Team, and are nearly the same as those from the previous CHE study (see Appendix H of the STER, Anchor QEA and Coast and Harbor Engineering, 2012).

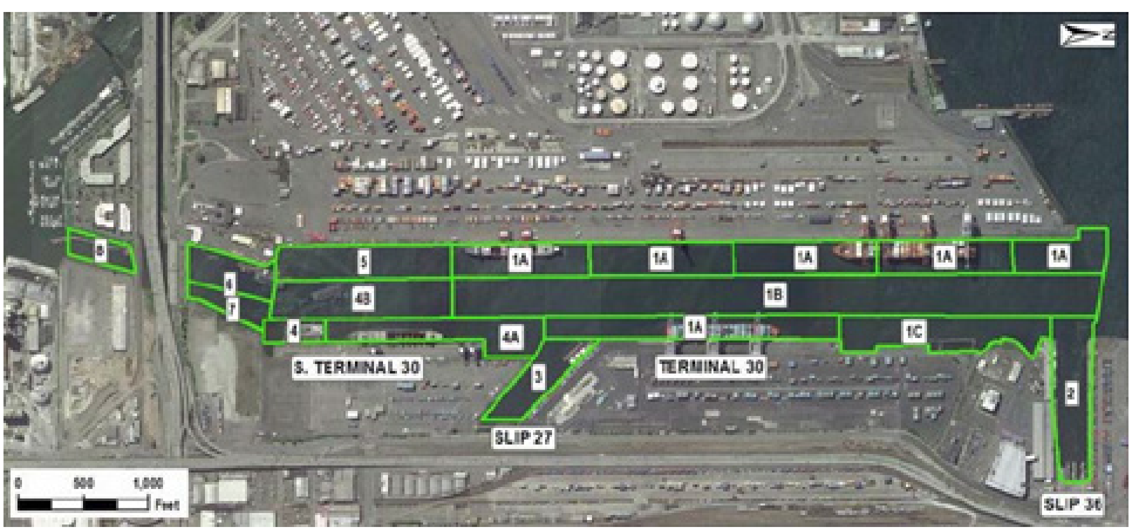

Figure 2. Delineated operational areas for scour prediction values

The largest ships represented by Xin Mei Zhou are assumed to dock only at the northern end of Terminal 18, which is in three of the delineated areas “1A.” Depressions of deeper bathymetry are also located in this area. At all other 1A areas, the limiting ship is the smaller Margit Rickmers. These assumptions are consistent with vessel operations outlined in Section 5 of the Final Sediment Transport Evaluation Report (Anchor QEA and Coast and Harbor Engineering, 2012).

As ships pass over potential scour locations, the near bottom velocities due to propwash at a single point change over time. The assumed conservative estimate of sideways ship velocity within the East Waterway is 2 feet per second. Therefore, the JETWASH velocity at a single point changes over time and is sensitive to ship speed.

Because the scour scenarios were evaluated at several extreme (MLLW, thruster/prop power) and unique (exact berthing location) conditions, the probability of such conditions occurring together multiple times is very low (i.e., 10% * 10% * 10% = 0.1%). This technical memorandum determines scour from a single, conservative, and rare event.

3. Results

Based on this analysis, depth of scour in the East Waterway will range from 4.7 ft on the high end for container ships, to 0.3 ft on the low end for tugs in deep water. Because scour is extremely complicated, a range of scour depth values for each location was determined based on a range of values for empirical coefficients. Presented here are results based on applying the conservative value of that range.

Results of scour depth calculation for each operational area are shown in Figure 3 in color format. Please note that the color represents the maximum localized depth of scour that may occur inside the delineated area. It other words, the computed depth of scour presented here would occupy a much smaller area than that shown in the figure.

The results of computation demonstrate that the greatest depth of scour (4.7 ft) would occur at Berths 1 and 2 of Terminal 18 due to bow thrusters. The scoured areas shown in the figure in red (0.3 ft) and orange (0.7 ft) resulted from tugs. The tugs operate in deep water with shallower propeller draft, thus generating much less scour. Area 6 is an exception. In this location, tugs operate by docking barges in relatively shallow water (20 ft), which results in 2.9 ft of scour, much more than other tug cases.

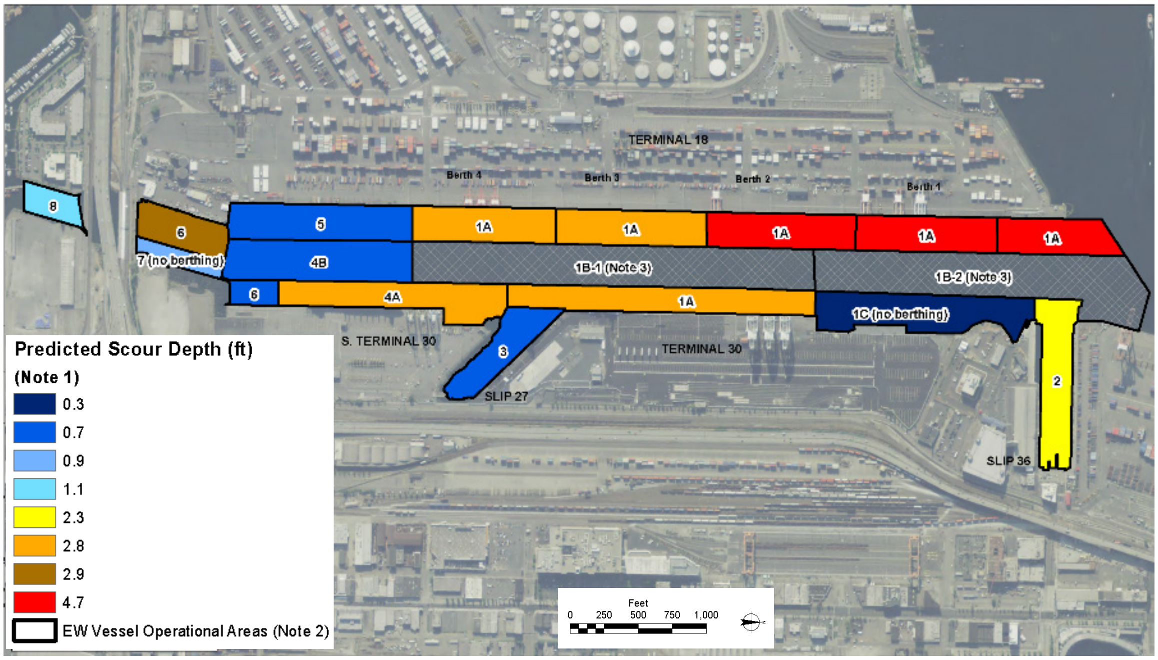

Figure 3. Predicted scour depths from vessel operations

Notes:
1. Calculations for scour depths provided in Attachment 4 of Appendix F.
2. EW Vessel Operational Areas developed as part of the EW STER (Anchor QEA and Coast and Harbor Engineering, 2012); see Section 5.1.2 of the STER.
3. Areas 1B-1 and 1B-2 represent the navigation area between Terminal 18 and 30 berthing areas. Since berthing maneuvers may begin within the navigation channel depending on weather or other site conditions, this area is expected to experience similar scour depths as the berthing areas.

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PART 3A: DREDGE RESIDUALS AND REPLACEMENT VALUE ESTIMATES

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1 INTRODUCTION

As described in Section 5.2 of the East Waterway (EW) Feasibility Study (FS), replacement values represent the estimated chemical concentrations in the top 10 centimeters (cm) of sediment following remediation. The replacement value only represents the initial (or Time 0) sediment condition in the top 10 cm following completion of remediation. The replacement values are influenced by the type of remediation performed (i.e., dredging, capping, in situ treatment, enhanced natural recovery [ENR], monitored natural recovery [MNR], or no action), pre-remediation conditions (e.g., concentrations prior to remediation), physical site conditions (e.g., sediment mixing during placement of residuals management cover [RMC]), and type of remediation performed in adjacent areas. This appendix describes the rationale for the estimate of replacement values for the human health risk-driver contaminants of concern (COCs; total polychlorinated biphenyls [PCBs], arsenic, carcinogenic polycyclic aromatic hydrocarbons [cPAHs], and dioxins/furans) to predict concentrations following construction and serve as inputs for model-predicted long-term concentrations for the purpose of comparing FS alternatives.

2 REMOVAL AREAS

All remedial alternatives use dredging (i.e., removal) as a primary remediation technology (FS Section 8). As described in Appendix B, Part 5, and FS Section 7.2.6.5, the generation of dredging residuals is inherent to the dredging process, due to the loss and redeposition of sediment during each dredging pass. All dredging projects result in some degree of resuspension, release, and residuals (NRC 2007). Generated dredging residuals are the sediment that is resuspended during dredging due to removal equipment limitations in preventing loss of particulate material during the action of dredging. The particulate material that settles is the generated residuals. Estimating the concentration and thickness in dredging residuals is important for estimating the concentrations in sediment that can be achieve following environmental dredging. Note that this appendix only calculates generated residuals and assumes the undisturbed residuals, or missed inventory, are addressed before the end of construction. In this appendix, the general term “residuals” is used to signify generated residuals only. The following section describes the estimate of generated dredging residuals concentration and thickness, and the resulting replacement values in dredging areas. Section 3 of this appendix describes replacement values for other technology areas.

2.1 Estimating Dredging Residuals

As described in FS Appendix B, Part 5, the nature and extent of residuals is dependent on the dredging equipment and methods, the sediment geotechnical characteristics, the magnitude and distribution of sediment contaminants, and the physical site conditions (e.g., erosional/depositional regime, and presence of rock, debris, and bedrock). Due to this complex interrelationship, there are no commonly used numerical methods or models to reliably predict post-dredging residual concentrations with a high level of accuracy. In the absence of predictive models, “bounding-level” estimates of the thickness and chemical composition of the post-dredging residual layer may be developed using standard mass balance equations and site-specific physical and chemical properties, as described in Patmont and Palermo (2007), and USACE (2008a, 2008b). Generally, bounding-level estimates of COC concentrations are calculated based on the average sediment concentration in the final production cut. If multiple dredge passes have occurred, the generated residuals from the previous passes are estimated and included in the profile of the final production cut, which is then used to estimate the final residual concentrations (Patmont and Palermo 2007; USACE 2008a). As such, these dredge residual estimates are intended to provide a general approximation of the range of *potential* residual thicknesses and concentrations that may be generated by remedial dredging of the EW.

The dredge residuals estimate developed for the EW FS for total PCBs, cPAHs, and arsenic uses the following approach (dioxins/furans are discussed in Section 2.1.6 herein):

1. Select the representative area of interest and the sediment cores for performing the analysis.
2. Estimate the dredge depth based on contamination thickness and number of dredge passes for each core location.
3. Estimate the dredge residuals thickness and concentration for each core location based on an estimated percent loss of dredge material during each dredge pass (the best estimate is 5% loss of dredged material, based on case studies).
4. Calculate the spatially-weighted average residuals thickness and concentration within the area of interest.
5. Revise the input parameters analysis for the purpose of sensitivity and bounding runs.

The following sections describe these steps.

2.1.1 Selection of Cores for Analysis

The representative area of interest for this analysis is the area exceeding the remedial action levels (RALs) for all COCs, including using 12 milligrams per kilogram (mg/kg) organic carbon (OC) for PCBs (FS Section 6). This representative area of interest encompasses 121 of 156 acres of the waterway, and is the remediation footprint for the majority of alternatives developed in the FS. Sediment cores in the FS baseline dataset within this area that have not been dredged since samples have been collected were included in the analysis.

All sediment cores within the representative area of interest were used as a single set of cores, which was considered representative of all alternatives for this analysis because all FS alternatives rely primarily on dredging (from 68 acres 139 acres of removal depending on the alternative; FS Section 8). Moreover, an exploratory analysis found that restricting the analysis to cores within each alternative's specific removal area only made a minor difference on the residuals concentration and thickness estimate, due to steep horizontal and vertical concentration gradients in the EW. The exploratory analysis found that the differences in residuals concentrations and thicknesses between alternatives was less than the range in the sensitivity evaluation (Section 2.1.5). Therefore, the sensitivity analysis encompasses the potential range in residuals concentrations and thicknesses for all the alternatives, and a single set of cores is appropriate for all alternatives.

2.1.2 Dredging Methodology Assumptions

As described in FS Appendix F, the dredge prism is designed to remove sediments exceeding RALs. To estimate the thickness and concentration of post-dredging residuals, the contaminated sediment neatline surface was used to estimate the depth of contamination and thus the estimated dredge cut thickness and the number of potential dredge passes at each core location, assuming 1 foot of overdredge (FS Appendix F develops the contaminated neatline surface). The final required dredge elevations and the overdredge allowance will be specified in design.

Dredging assumptions used in the residuals calculations are the following:

- The maximum lift of contaminated sediment removed in any individual dredging pass will be 4 feet.
- The first pass cut for the removal of contaminated sediment was estimated to be from mudline to the base of the contaminated neatline surface plus 1 foot of overdredge, but not greater than 4 feet.
- The second pass for the removal of contaminated sediment, if necessary, was estimated to be from the base of the first dredge cut (4 feet) to the base of the contaminated neatline surface plus 1 foot of overdredge. This cut consists of the residual layer generated during the first pass, additional contaminated sediment targeted for removal, and overdredge material (less than the RAL).
- Additional passes for the removal of contaminated sediment, if necessary, follow the same methodology described for the second dredge pass.
- The ultimate residuals layer thickness for each location was estimated based on the thickness of sediment being removed in the last dredge pass and the assumed percent

material lost as generated residuals. Because the thickness of the residual layer is based on the percent of material lost in the final dredging pass, areas with more sediment removal in the last dredge pass are predicted to have a thicker residuals layer.

2.1.3 Estimating the Residual Layer Thickness and Concentration

Figure 1 provides a graphical description of the approach for calculating the estimated concentration of COCs in the generated residuals. The residuals calculations for the EW were estimated using the vertically-weighted average concentration of sample intervals within each dredge cut. Sediment core intervals that were not analyzed were assumed to have the contaminant concentration of the sediment core interval analyzed immediately above. In addition, cores that did not extend down to the full dredging depth (i.e., cores that did not reach the base of contamination because they exceed RALs in the deepest sample interval analyzed) were assumed to have the concentration of the sediment core interval analyzed immediately above all the way down to the contaminated neatline surface. Below the contaminated neatline surface (i.e., within the overdredge interval), sediment does not exceed RALs, and cores without concentration data were assumed to equal have the site-wide average concentration in sediment below the neatline surface.

In the areas that were assumed to require only a single dredging pass, the estimated residual concentration is equal to the depth-weighted average of the sediment in the first full dredge cut. In the areas that were assumed to require two or more dredging passes, the influence of generated residuals from the first pass was considered in the depth-weighting averaging of the second and final residuals concentrations. Ultimately, a single residual layer of estimated thickness (based on dredge depth, number of dredge passes, and assumed residuals generation rates) with unique concentrations for each COC was determined at each core location.

For a single-pass dredging location, the residuals thickness is estimated as follows:

$$Tr_1 = L_U Td_1$$

For a dredging location with two or more dredge passes, the residuals thickness is calculated for each dredge cut in series, considering the residuals from the previous dredge cut as follows:

$$Tr_n = L_U Td_n + L_R L_U Td_{(n-1)}$$

where:

Tr_1	=	thickness of the residual layer after first dredge pass
Tr_n	=	thickness of the residual layer after the n^{th} dredge pass
L_U	=	percent loss of undredged native material (best estimate = 5%)
L_R	=	percent loss of redredged residuals material (50%)
Td_1	=	thickness of first dredge pass
Td_n	=	thickness of the n^{th} dredge pass

The final residuals thickness is the thickness following the last dredge pass in a location. As discussed in Section 2.2 of this appendix, case studies indicate that an average of 5% of the contaminant mass in a dredge cut will be lost and will resettle as a post-dredge residual layer. Case studies also show the diminishing returns of redredging deposited residuals; therefore, redredging is expected to result in more loss of the deposited residuals from previous dredge cuts at that location. This is primarily due to the unconsolidated nature of the dredge residuals layer, which make it more prone to loss during the dredging process. For this project, a loss rate of 50% of the redredged residuals layer is modeled.

Contingency redredging of dredge residuals (after completion of production dredging) could affect site-wide post-dredging surface sediment concentrations. However, redredging is not included in the calculations of post-dredge residuals concentration and thickness for the remedial alternatives. FS Appendix B, Part 5, describes the range of dredging residuals management approaches, including redredging, that could be developed during design and construction to manage dredge residuals and ultimately affect site-wide post-construction concentrations. In general, redredging for residual management will remove additional contaminant mass, but is ineffective at reducing surface sediment concentrations (Patmont and Palermo 2007). Other methods, such as placement of RMC, have been shown to be more effective at reducing site-wide concentrations than additional redredge passes after completion of production dredging (e.g., Esquimalt Graving Dock Remediation project [British Columbia; Berlin et al. 2017], Lower Fox River [Wisconsin], Hudson River Phase 2 [New York], and others [Patmont et al., 2017; Bridges et al., 2010]).

2.1.4 Calculating Site-wide Average Thickness and Concentration of the Residuals Layer

After the residuals concentration and thickness were calculated using the data associated with each core, the site-wide average was calculated by assigning each core to an area based on a Thiessen polygon network generated from the core locations. The area of each Thiessen polygon was used to weight each core by the relative area that the core represents to generate a spatially-weighted average for both residuals concentration and thickness.

2.1.5 Residuals Values for Sensitivity Analysis

Residuals thickness and concentration inputs were varied as part of the box model sensitivity analysis for total PCBs (FS Appendix J). Residuals thickness was varied based on the case studies presented in FS Appendix B, Part 5. The low bound sensitivity analysis was calculated assuming 3% loss of dredge material during first pass dredging. The high bound sensitivity analysis was calculated assuming 7% loss of dredge material during first pass dredging based on Patmont and Palermo (2007).

Residuals concentration was varied based on analyzing the results of the core-by-core dredge residual analysis. The low value was estimated by selecting the median concentration of cores. The high value was estimated to be the 95% upper confidence limit on the mean (UCL95) (gamma distribution) of cores.

2.1.6 Residuals Estimate for Dioxins/Furans

Dioxins/furans were analyzed in a subset of cores in the FS dataset, and thus there was not sufficient data to perform the analysis described above, which considers dredge depths, multiple dredge passes, and area-weighted averaging. As a simplified analysis, all dioxin/furan core interval samples within the area of interest were averaged. One core location, EW10-SC23, was excluded from the analysis because the core is located at the head of Slip 27 in an area that will be capped (without any dredging). The resulting average concentration for all remaining cores is 17 nanograms toxic equivalent per kilogram (ng TEQ/kg) dry weight (dw) and this value is used for the concentration of dioxins/furans in residuals.

2.2 Estimating the Replacement Value in Removal Areas

FS Appendix B, Part 5 compares a number of dredging residuals management approaches that could be developed during design and construction to manage dredge residuals. For purposes of FS alternative detailed and comparative analysis, all FS alternatives are assumed to use the same residuals management approach: a RMC layer. RMC is a thin layer (e.g., 9 inch average thickness, to be confirmed during design) of clean quarry sand designed to reduce concentrations in the biologically active zone (BAZ) following dredging. Although sand is expected to have concentrations similar to natural background, some degree of resuspension and redeposition of residuals is expected during placement because of the less consolidated nature of dredge residuals. It is estimated that 10% of the residuals layer would resuspend and redeposit on the RMC sand layer. The resulting vertically weighted average concentration in the BAZ (upper 10 cm) in sediment following placement (i.e., the "replacement value") is calculated from the following equation:

$$C_{BR} = (L_S Tr_f Cr_f + (T_{BR} - L_S Tr_f)C_{SC})/T_{BR}$$

where:

C_{BR}	=	concentration in the biologically active zone (the bed replacement value; calculated; presented in Table 1)
C_{SC}	=	concentration in residuals management cover (sediment cover; PCBs = 2 µg/kg dw, cPAHs = 9 µg TEQ/kg dw, dioxins/furans = 2 ng TEQ/kg dw, arsenic = 4 mg/kg dw)
Cr_f	=	concentration of residuals after the final dredge pass (presented in Table 1 based on the calculation described in Section 2.1)
T_{BR}	=	thickness of the biologically active zone (thickness of the bed replacement layer = 10 cm)
Tr_f	=	thickness of the residual layer after the final dredge pass (5.1 cm for the best estimate)
L_S	=	percent of residuals resuspension and redeposition during residuals management cover placement (10% of the residuals thickness layer [Tr_f])

2.3 Estimating the Replacement Value Adjacent to Removal Areas

ENR-nav, ENR-sill, and the interior unremediated islands are all remediation areas that incorporate thin layer placement of sand (as described in FS Section 5.2, unremediated interior islands are assumed to have RMC placement, but the need for such placement will be determined during design and based on post-dredge sampling). These areas do not include removal; however, removal in adjacent areas is assumed to influence these areas from generated residuals from nearby dredging operations. For this analysis, thickness of dredging residuals is estimated to be 1/5 of the thickness of dredging residuals within the removal footprint.

2.4 Results

The results for the residuals analysis and replacement value calculation are presented in Table 1.

Table 1
Replacement Values and Residuals in Removal and Adjacent Areas

Parameter		Best Estimate	Low Sensitivity	High Sensitivity
Removal Areas				
Replacement Value for removal areas (Post-construction Concentration)	Total PCBs (µg/kg dw)	35	17	72
	cPAHs (µg TEQ/kg dw)	34	nc	nc
	Arsenic (mg/kg dw)	4.3	nc	nc
	Dioxins/furans (ng TEQ/kg dw)	2.8	nc	nc
Dredge Residuals Thickness in Dredged Areas (cm)		5.1	3.1	7.2
Dredge Residuals Concentration	Total PCBs (µg/kg dw)	640	470	980
	cPAHs (µg TEQ/kg dw)	490	nc	nc
	Arsenic (mg/kg dw)	10	nc	nc
	Dioxins/furans (ng TEQ/kg dw)	17	nc	nc

Areas Adjacent to Removal Areas (ENR-nav, ENR-sill, and Interior Unremediated Islands)				
Replacement Value (Post-construction Concentration)	Total PCBs (µg/kg dw)	8.4	5.8	11
	cPAHs (µg TEQ/kg dw)	14	nc	nc
	Arsenic (mg/kg dw)	4.1	nc	nc
	Dioxins/furans (ng TEQ/kg dw)	2.2	nc	nc
Dredge Residuals Thickness in Areas Adjacent to Dredged Areas (cm)		1.0	0.6	1.4
Dredge Residuals Concentration		Same as above		

Notes:
µg/kg – microgram per kilogram
cm – centimeter
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
FS – Feasibility Study
mg/kg – milligram per kilogram
nc – not calculated
ng – nanogram
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

3 ALL REMEDIAL TECHNOLOGY AREAS

Table 2 presents the replacement values and rationale for all remedial technology areas for the alternatives. FS Appendix J, Table 2, presents the replacement values for all remedial technology area for all alternatives (including the alternative-specific inputs not included in Table 2 below).

Table 2
Replacement Values for Technology Areas

Technology Area	Total PCBs (µg/kg dw)	cPAHs (µg TEQ/kg dw)	Dioxins/ Furans (ng TEQ/kg dw)	Arsenic (mg/kg dw)	Rationale
Open-water Areas					
Removal	35	34	2.8	4.3	See Section 2 herein. Assume that RMC is placed following dredging.
Partial Removal and Capping	2	9	2	4	Estimated concentration in quarry sand.
Partial Removal and ENR-nav	35	34	2.8	4.3	Values assumed to be consistent with dredging.
ENR-nav, ENR-sill and Interior Unremediated Islands	8.4	14	2.2	4.1	Some influence from adjacent removal areas
Exterior Unremediated Islands	Post-construction SWAC assumed to be equal to baseline (pre-remediation) SWAC (alternative-specific).				No remediation; assume negligible influence from adjacent areas.
Underpier					
MNR	Post-construction SWAC assumed to be equal to baseline (pre-remediation) SWAC (alternative-specific)				No remediation; see Section 3 herein.
In situ Treatment	Pre-remediation SWAC reduced by 70% of original (FS Section 7.2.7.1). Alternative-specific.			Volume-weighted average dry weight-based concentration of baseline sediment plus 3 inches placement material (alternative-specific).	Underpier modeling was performed using a volume-based approach for the volume of sediment above riprap.

Technology Area	Total PCBs (µg/kg dw)	cPAHs (µg TEQ/kg dw)	Dioxins/ Furans (ng TEQ/kg dw)	Arsenic (mg/kg dw)	Rationale
Dredging Followed by In situ Treatment	Pre-remediation SWAC reduced by 70% of original (FS Section 7.2.7.1). Alternative-specific.			Volume-weighted average dry weight-based concentration of baseline sediment plus placement material (alternative-specific).	Underpier modeling was performed using a volume-based approach for the volume of sediment above riprap. Ten-centimeter depth of sediment is assumed to remain following dredging.

Notes:
See FS Appendix J, Table 2, for alternative-specific replacement values for all alternatives.
See FS Appendix J, Section 2.3, for mixing assumptions used in modeling.
µg/kg – microgram per kilogram
cm – centimeter
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
ENR – enhanced natural recovery
FS – Feasibility Study
mg/kg – milligram per kilogram
MNR – monitored natural recovery
ng/kg – nanogram per kilogram
PCB – polychlorinated biphenyl
RMC – residuals management cover
SWAC – spatially-weighted average concentration
TEQ – toxic equivalent

Partial dredging and capping areas are assumed to have the post-construction concentration equal to the estimated concentration in quarry material placed in these areas for capping purposes. Because of the thickness of placed capping material, dredge residuals are not anticipated to have large impact on the post-construction concentration. In addition, caps are assumed to be constructed after dredging of adjacent areas has been completed, minimizing the influence of resuspended sediment from dredging operations occurring elsewhere in the EW after cap placement. For organic compounds (total PCBs, cPAHS, and dioxins/furans), due to lack of detected concentration data in quarry material, replacement values are based on natural background. For arsenic, the concentration of 4 mg/kg dw was estimated based on the average of 22 samples provided by quarry sources from recent in-water placement projects, which ranged from 1 mg/kg dw to 7 mg/kg dw in concentration.

Partial dredging and ENR-nav areas are assumed to have the same replacement value as dredging areas because dredging followed by ENR-nav sand placement follows a similar process as full dredging followed by RMC placement.

The replacement value estimates for ENR-nav, ENR-sill, and the interior unremediated islands are based on the influence associated with extensive removal in adjacent areas, as described in Section 2.3. These areas are assumed to have a thin layer of dredging residuals (1 cm for the best estimate) followed by sand placement. The replacement values include the influence or resuspended dredge residuals and the concentration in sand cover.

Exterior unremediated islands are only adjacent to dredging operations on one side, as opposed to interior unremediated islands that are surrounded by dredging operations on all sides. Therefore, exterior unremediated islands are assumed to be negligibly influenced by dredge residuals from adjacent areas, and therefore are assumed to not require RMC placement. Consequently, the areas are assumed to have the concentrations equivalent to pre-construction conditions.

Underpier modeling was performed using a volume-based approach for the volume of sediment above riprap (see FS Appendix J, Section 2.3.5). The volume-based approach was developed to accommodate the modeling of exchange of sediments between open-water areas and underpier areas. The average thickness of sediment deposited on underpier riprap is 2.3 feet (see FS Section 8.1.1.6 and Appendix F for additional detail), generally consistent with the box-model mixing depth in areas adjacent to underpier areas.

Underpier MNR areas are assumed to be minimally influenced by dredge residuals from adjacent areas because pre-construction sediment concentrations in underpier areas are similar to predicted concentrations in residuals and because adjacent dredging occurs only along one edge of the underpier areas.

Underpier in situ treatment areas are assumed to have a reduction of 70% from pre-construction concentrations for hydrophobic organic compounds (total PCBs, cPAHs, and dioxins/furans) based on pilot studies, bench studies, and guidance considering the potential for burial, mixing, and loss of AC material from propwash forces (FS Section 7.2.7.1). For arsenic, replacement value concentrations are based on the volume-weighted average dry weight-based concentration of baseline sediment plus 3 inches of in situ treatment placement material.

Underpier hydraulic dredging areas are assumed to result in 10 cm of residuals left behind that have concentrations equivalent to pre-dredging volume-weighted concentrations. When in situ treatment follows hydraulic dredging, the post-construction concentrations are calculated consistent with in situ treatment described above (but with the reduction in initial volume).

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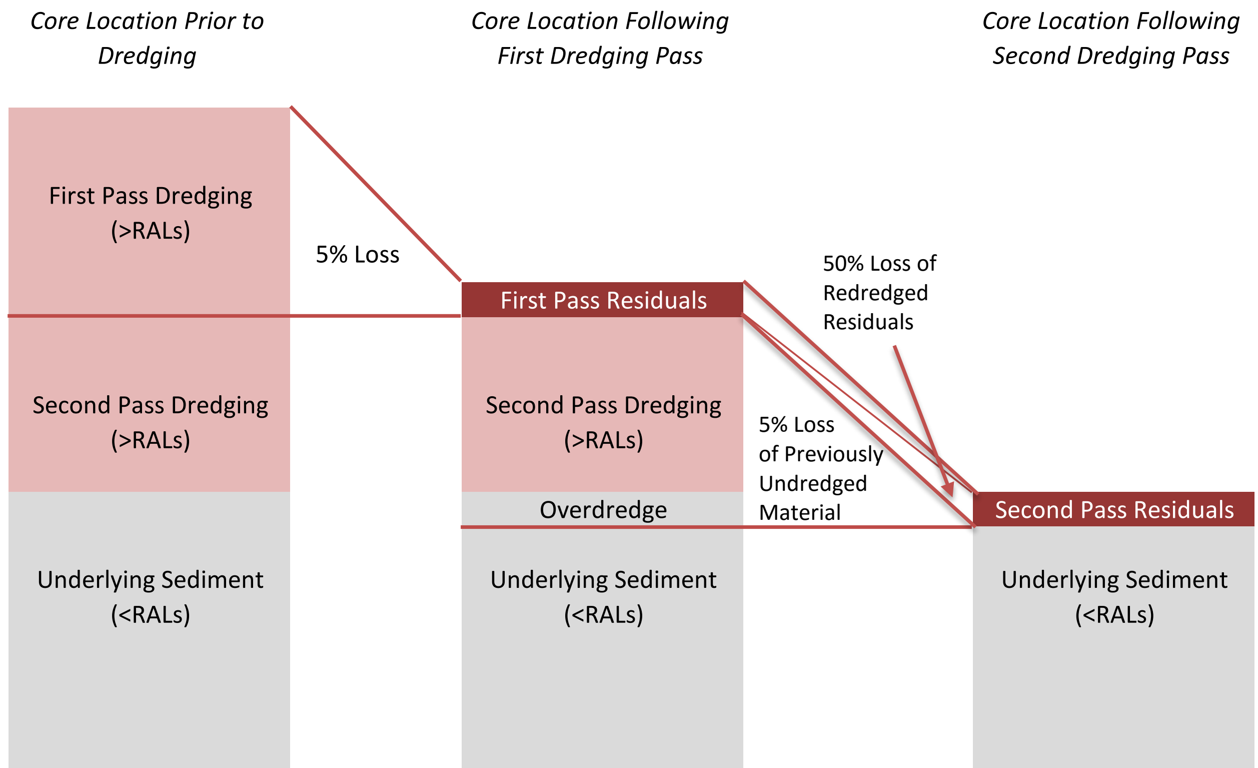
FIGURE



Notes and Assumptions

1. The residuals analysis was performed at each core located within the RAL footprint (using 12 mg/kg OC for PCBs; FS Section 6).
2. The number of dredge passes at each core location was based on a 4-foot maximum dredge cut (e.g., cores with dredge depths from 4 to 8 feet required two dredge passes).
3. The concentration in residuals resulting from the first dredge pass was equal to the vertical weighted average concentration in the core sample intervals that overlap with the first pass dredge interval.
4. The thickness of residuals resulting from the first dredge pass was based on 5% loss of dredged material.
5. The concentration in residuals resulting from subsequent dredge passes (i.e., two or more dredge passes) was equal to the vertical weighted average concentration in the core sample intervals that overlap with the dredge interval, averaged with residuals from the first dredge pass. The dredge interval material and the first pass residuals were weighted appropriately based on the starting thickness and
6. The thickness of residuals resulting from subsequent dredge passes (i.e., two or more dredge passes) was based on 5% loss of previously undredged material plus 50% loss of redredged residuals. The loss of redredged residuals was based on empirical evidence from other projects of diminishing returns from redredging.
7. The last dredge cut included an additional 1 foot of overdredge based on a typical construction tolerance.
8. The average sediment PCBs concentration in underlying sediment below the contaminated neatline surface was 15 µg/kg dw.
9. The area-wide average residuals concentration and thickness were calculated based on the concentration and thickness in each core following the last dredge pass, then area-weighted averaged based on Theissen polygon areas.

µg/kg – microgram per kilogram
dw – dry weight
FS – Feasibility Study
mg/kg – milligram per kilogram
OC – organic carbon
PCB – polychlorinated biphenyl
RAL – remedial action level

Figure 1
Example Diagram Showing Residuals Calculation for Location with Two Dredge Passes
Feasibility Study - Appendix B, Part 3A
East Waterway Study Area

PART 3B: GREEN RIVER INPUTS

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1 INTRODUCTION

Contaminant concentrations associated with Green River solids were compiled from various data sources from the Lower Duwamish Waterway (LDW) Feasibility Study (FS) (AECOM 2012). These data provide multiple lines of evidence that characterize the contaminant concentrations associated with sediments entering the LDW from the Green River, which can also be used to estimate the Green River concentrations entering the East Waterway (EW). A detailed description and detailed evaluation is presented in the LDW FS (AECOM 2012; Section 5.2.3.1 and Appendix C, Part 3), which was the result of an extensive data screening and evaluation process in consultation with EPA. Estimates for concentrations of sediments entering the EW rely on much of the analysis performed for the LDW, and are therefore referenced where appropriate.

Arsenic, total PCB (polychlorinated biphenyl), dioxin and furans (dioxin/furans), and carcinogenic polycyclic aromatic hydrocarbons (cPAHs) upstream values were presented in the LDW FS (AECOM 2012; Tables 5-2a through 5-2d). Upstream data presented in the LDW FS baseline dataset (AECOM 2012) were further evaluated specifically for use in the EW for arsenic, total PCBs[1], dioxin/furans, and cPAHs (human health risk driver contaminants of concern [COCs]) for evaluation of the remedial action objectives (RAOs) 1 and 2 (human health resident seafood consumption and direct contact pathways, respectively) and recontamination potential. Five additional benthic invertebrate risk driver COCs—bis(2-ethylhexyl)phthalate (BEHP), low-molecular-weight polycyclic aromatic hydrocarbon (LPAH), high-molecular-weight polycyclic aromatic hydrocarbon (HPAH), mercury, and 1,4-dichlorobenzene—were also evaluated for RAO 3 (protection of benthic community) and recontamination potential. Data from the various upstream datasets were used to develop a range of values for the EW (Table 1).

[1] Total PCBs is also a risk driver COC for fish receptors of concern English sole and brown rockfish (RAO 4).

2 SUMMARY OF THE DATA SOURCES

As described in the LDW FS (AECOM 2012), the upstream data sources included the following:

- **Upstream whole water samples collected by King County.** Concentrations associated with suspended solids in the Green/Duwamish River inflow, based on upstream water quality monitoring data collected by King County from 2001 through 2008 (AECOM 2012; LDW FS baseline database).
- **Upstream centrifuged suspended solids samples collected by the Washington State Department of Ecology (Ecology).** Data from centrifuged solids samples collected in the Duwamish River upstream of the LDW by Ecology in 2008 and 2009 (Ecology 2009, as presented in the LDW FS baseline database).
- **Upstream surface sediment samples (containing fines greater than 30%) collected by Ecology.** Surface sediment samples collected in 2008 between river mile (RM) 4.9 and RM 6.5 by Ecology (AECOM 2012; LDW FS baseline database).
- **LDW RM 4.3 to 4.75 U.S. Army Corps of Engineers (USACE) core data.** USACE dredged material characterization core data collected from the upper reach of the LDW between RM 4.3 and RM 4.75 from 1990 through 2009 (USACE 2009a, 2009b, as presented in the LDW FS baseline database).

Each of these datasets is briefly summarized below. A detailed description and evaluation is presented in the LDW FS Section 5.2.3.1 and Appendix C, Part 3.

King County whole water samples were collected from two sampling locations that were located approximately 1.3 miles (Duwamish River at Marginal Way; RM 6.3) and 5.9 miles (Green River at Fort Dent; RM 10.9) upstream of the LDW. These samples were collected as part of King County's routine monthly stream sampling and as part of targeted wet weather event sampling. The upstream King County whole water concentrations were normalized to the value of the concurrently collected total suspended solids (TSS), so that the concentration units were comparable with the sediment concentration units (i.e., both on a dry weight basis)[2].

Centrifuged solids data were collected by Ecology (Ecology 2009), upstream of the LDW at RM 6.7. Samples of suspended material were collected during seven sampling events at this location during varying flow conditions and during one storm event. These Ecology samples are generally representative of sediments suspended mid-channel in the Green River that could settle in both LDW and EW.

A subset of the Ecology upstream surface sediment data was developed by excluding samples that contained less than 30% fines. This approach acknowledges the systematic differences in grain size distributions between upstream sediment data and average sediment conditions in the LDW and EW. This dataset represents sediments just upstream of the LDW that can be resuspended under high-flow conditions, transported, and redeposited downstream.

The subsurface sediment cores collected by USACE from RM 4.3 to 4.75 represent sediment from the Green River that settles in the upper reach of the LDW, since the upper reach functions as a sediment trap for approximately one-third of the upstream sediment. Because dredging is conducted every 2 to 4 years from RM 4.0 to 4.75, this area is a good indicator of recent suspended solids from the Green River (AECOM 2012). However, the majority of the solids that settle in this area are coarser grain material than sediment typically found farther downstream in the rest of the LDW and the EW.

Since the development of the Green River datasets used for the LDW FS, new data have been collected on the Green River, including the four human health risk driver contaminants (King County 2016; USGS 2016). No additional modeling that would include these new data has been undertaken, for several reasons:

- The U.S. Geological Survey is still reviewing and processing their data, and will present their estimates of upstream concentrations.

[2] Normalizing to TSS likely produces a high estimate of the COC concentration on sediment particles because some of the COC mass is likely dissolved or on colloidal particles that do not settle in the LDW and may not settle in the EW.

- Based on a review of the preliminary USGS data and King County data, these data are within the range of values previously used in the modeling, and therefore incorporating these data would not change the concentration range presented in the sensitivity and bounding analysis in Section 2.3 of FS Appendix J.
- Any minor changes in results from incorporating these data into an additional modeling effort would have an equal bearing on all alternatives, and therefore would not affect the conclusions of the EW FS.

A summary of the preliminary data, and a comparison of these data with original FS box model inputs, is provided in Table 3.

3 CHEMICAL CONCENTRATIONS

The selected upstream solids values were based on these four datasets to represent the best estimate concentrations of the four human health risk driver COCs and five additional benthic risk driver COCs entering the EW. These datasets are considered reasonable lines of evidence for developing incoming concentrations to the EW from the Green River, although each type of data collection tends to bias the results toward lower or higher values (e.g., low percent fines versus high percent fines; single collection events versus seasonal collection events; and the potential influence of sources). In general, the value representing a mid-range of the various lines of evidence was considered for the input value, and then values representing upper and lower bounds were selected for the high and low sensitivity input values, respectively. One goal of including a range in the input values is to account for uncertainty in all the datasets representing upstream inputs from the Green River, and show how these data ranges affect the predictions of long-term site performance for the remedial alternatives.

The input values are presented as dry weight concentrations for the selected COCs. Dry weight concentrations may be biased low and may underrepresent the concentrations associated with the fraction of solids entering the EW that have finer grain size and higher organic carbon concentrations. Silt- and clay-sized suspended solids are estimated to be 67% of the sediment entering the LDW, but more than 99% of the sediment entering the EW (Anchor QEA and Coast & Harbor Engineering 2012). Additional discussion of the data evaluation and selection process for upstream chemistry inputs used in the LDW is provided in the LDW FS Section 5.3.3 and Appendix C, Part 3 (AECOM 2012).

3.1 Human Health Risk Driver COCs

For total PCBs and cPAHs, the means of the combined Ecology centrifuged TSS data and King County whole water data were selected as the upstream input values (42 microgram per kilogram dry weight [µg/kg dw] and 140 µg toxic equivalent [TEQ]/kg dw, respectively). For the LDW FS (AECOM 2012), total PCBs and cPAHs were estimated using the mean of the LDW RM 4.3 to 4.75 USACE core data. However, the Ecology centrifuged TSS data and King County whole water data are more appropriate to estimate the concentration of Green River solids entering the EW because of the high percentage of fine-grained sediment (silt/clay) that enters the EW. Based on the LDW Sediment Transport Model (STM), little to no coarse-grained particles (i.e., sand) enter the EW (less than 1%), which contrasts with the LDW where coarse-grained particles make up approximately 33% of sediment input from the Green River.

To address sensitivity around the mid-range value for both total PCBs and cPAHs, the low upstream input values were the means of the Ecology upstream surface sediment sample data containing fines greater than 30% (5 µg/kg dw and 40 µg TEQ/kg dw, respectively). The high upstream input values were the 95% upper confidence limit on the means (UCL95) of the TSS-normalized King County whole water datasets (80 µg/kg dw and 270 µg TEQ/kg dw, respectively). These low and high concentrations are consistent with the values used in the LDW FS.

For arsenic, the selected upstream input value was the mean (9 milligrams per kilogram dry weight [mg/kg dw]) of the Ecology upstream sample data containing fines greater than 30%. The mean of the LDW RM 4.3 to 4.75 USACE core data (7 mg/kg dw) was selected as the low sensitivity value. The high sensitivity value (10 mg/kg dw) was the UCL95 of the Ecology upstream sediment sample data containing fines greater than 30%. All arsenic concentrations are consistent with the values used in the LDW FS[3].

For dioxin/furans, the mean of the Ecology centrifuged TSS data was selected as the input value (6 ng TEQ/kg dw). For the LDW FS, dioxin/furans were estimated using the mean of the Ecology centrifuged TSS data and the Ecology upstream sediment samples containing greater than 30% fines. The Ecology centrifuged TSS data is more appropriate to estimate the concentration of Green River solids entering the EW because of the high percentage of fine-grained sediment (silt/clay) that enters the EW. The low sensitivity value is the mean of the Ecology upstream sediment sample data containing fines greater than 30% (2 ng TEQ/kg

[3] As described in LDW FS (AECOM 2012; Section 5.2.3.1), King County surface water TSS-normalized data and Ecology centrifuged solids data were not used in the selection of upstream values for arsenic because the UCL95 for both of these datasets would have resulted in much higher modeled surface sediment concentrations than in the EW and LDW baseline datasets. It is likely that these two datasets, especially the surface water dataset, contain very fine particulates (e.g., clays) with higher arsenic concentrations than those that deposit in the EW and LDW. Very fine particles (e.g., clays) tend not to settle in the EW and LDW.

dw); and the high sensitivity value is the midpoint between the mean and UCL95 of the Ecology upstream centrifuged solids dataset (8 ng TEQ/kg dw). These low and high concentrations are consistent with the values used in the LDW FS (AECOM 2012).

3.2 Benthic Risk Driver COCs

Only the best estimate input values (no low or high sensitivity values) were presented in the LDW FS (AECOM 2012) for a limited number of SMS chemicals. Low and high sensitivity values were not developed for non-human health risk drivers because they were not evaluated as part of the upstream chemistry sensitivity analysis. Of the SMS chemicals evaluated in the LDW FS (see LDW FS Table 5-3), only BEHP and mercury inputs were evaluated in the EW. The best estimate Green River input concentrations for the EW were unchanged from the LDW FS for these COCs. Best estimate Green River input concentrations were also estimated for LPAH, HPAH, and 1,4-dichlorobenzene for the EW. Statistics on the lines of evidence considered for benthic risk driver COCs are presented in Table 2. Selected base case Green River input concentrations for the EW are listed below:

- For HPAHs, the means of the combined Ecology centrifuged TSS data and King County whole water data were selected as the upstream input values (1,300 µg/kg dw). This value was selected because the King County whole water data and Ecology centrifuged TSS data measurements include a high percentage of fine-grained sediment (silt/clay) that is more representative of what enters the EW than other datasets.
- For LPAHs, the selected upstream input value was the mean of the Ecology centrifuged TSS data (130 µg/kg dw). This value was selected because the Ecology centrifuged TSS data measure a high percentage of fine-grained sediment (silt/clay) that is representative of what enters the EW. The King County whole water data were not included in this estimate based on project experience and best professional judgement. The whole water data include both dissolved and particulate-bound LPAHs and, therefore, whole water data tend to bias the estimated particulate concentrations high. Consistent with this interpretation, the estimated particulate concentration based on the King County whole water data were greater than EW baseline mean sediment concentrations. For these reasons, whole water data were not used for estimating upstream solids concentrations in LPAHs.

- For BEHP, the means of the combined Ecology upstream sample data containing fines greater than 30% and LDW RM 4.3 to 4.75 USACE core data were selected as the upstream input values (120 µg/kg dw), which is the same value used in the LDW FS. For BEHP, both datasets are valid for estimating the upstream load to the EW, so both datasets were retained. This is considered a reasonable best estimate from best professional judgement and project experience.
- For 1,4-dichlorobenzene, the means of the combined Ecology upstream sample data containing fines greater than 30% and LDW RM 4.3 to 4.75 USACE core data were selected as the upstream input values (1.2 µg/kg dw). This was selected based on analysis of all available data and for consistency with BEHP.
- For mercury, the selected upstream input value was the median of the LDW RM 4.3 to 4.75 USACE core data (0.1 mg/kg dw), consistent with the LDW FS (AECOM 2012). The median value was used to minimize the impact of outliers, which are common in sediment datasets for mercury.

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TABLES

Table 1
Green River Input Chemistry Used in East Waterway Modeling

Analyte	Best Estimate	Low	High	Basis for Input and Sensitivity Values
Total PCBs (µg/kg dw)	*42*	**5**	**80**	*Input: Mean of Ecology centrifuged TSS data and King County whole water data combined (see LDW Table 5-2a). Whole water data were used instead of LDW turning basin data (as used for the LDW FS) to account for finer fractions of sediment settling in the EW.* **Low: Mean of Ecology upstream sediment sample data containing fines >30% (see LDW Table 5-2a).** **High: UCL95 of TSS-normalized King County whole water data (value from LDW Table 5-2a; 82 rounded to 80 µg/kg dw).**
cPAHs (µg TEQ/kg dw)	*140*	**40**	**270**	*Input: Mean of Ecology centrifuged TSS data and King County whole water data combined (value from LDW Table 5-2c; 135 rounded to 140 µg TEQ/kg dw).* **Low: Mean of Ecology upstream sediment sample data containing fines >30% (value from LDW Table 5-2c; 37 rounded to 40 µg dw).** **High: UCL95 of TSS-normalized King County whole water data (value from LDW Table 5-2c; 269 rounded to 270 µg dw).**
Arsenic (mg/kg dw)	**9**	**7**	**10**	**Input: Mean of Ecology upstream sediment sample data containing fines >30% (see LDW Table 5-2b).** **Low: Mean of LDW RM 4.3 to 4.75 USACE (2001 to 2009) core data (see LDW Table 5-2b).** **High: UCL95 of Ecology upstream sediment sample data containing fines >30% (see LDW Table 5-2b).**
Dioxin/Furan (ng TEQ/kg dw)	*6*	**2**	**8**	*Input: Mean of Ecology centrifuged TSS data (see LDW Table 5-2d).* **Low: Mean of Ecology upstream sediment sample data containing fines >30% (see LDW Table 5-2d).** **High: Midpoint between mean and UCL95 of Ecology centrifuged solids data (see LDW Table 5-1a and LDW Table 5-2d).**
HPAHs (µg/kg dw)	1,300	NC	NC	Input: Mean of Ecology centrifuged TSS data and King County whole water data combined (calculated using LDW dataset).
LPAHs (µg/kg dw)	130	NC	NC	Input: Mean of Ecology centrifuged TSS data and King County whole water data combined (calculated using LDW dataset).
BEHP (µg/kg dw)	**120**	NC	NC	Input: Mean of combined Ecology upstream sediment sample data containing fines >30% and USACE RM 4.3 to 4.75 core data (calculated using LDW FS dataset).
1,4-dichlorobenzene (µg/kg dw)	1.2	NC	NC	Input: Mean combined of Ecology upstream sediment sample data containing fines >30% and USACE RM 4.3 to 4.75 core data (calculated using LDW FS dataset).
Mercury (mg/kg dw)	**0.1**	NC	NC	Input: Median of LDW RM 4.3 to 4.75 USACE (2008 to 2009) core data (calculated using LDW FS dataset).

Notes:

Italic = Presented in the LDW FS (AECOM 2012; Tables 5-2a, 5-2b, 5-2c, 5-2d, and 5-3).

Bold = Same as input values selected for LDW FS (LDW FS Table 5-1a through 5-1d or Table 5-3). The BEHP input value matched the LDW value, but was derived considering additional data.

In the LDW FS, Green River input values are as follows: total PCBs = 35 µg/kg dw, cPAHs = 70 µg TEQ/kg dw, arsenic = 9 mg/kg, dioxin/furan = 4 ng TEQ/kg dw, and BEHP = 120 µg/kg dw.

Non-detects were treated as 1/2 the reporting limit when calculating the mean and UCL95.

Data source: AECOM 2012. LDW Final FS Baseline Data Set. Available at http://ldwg.org/Assets/FS/Final_2012-10-31/LDW%20Final%20FS%20Baseline%20Dataset%20Files.zip.

NC = not calculated. Non-human health risk drivers were not evaluated as part of the upstream chemistry sensitivity analysis.

µg – microgram
BEHP – bis(2-ethylhexyl) phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
Ecology – Washington State Department of Ecology
EW – East Waterway
FS – Feasibility Study
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
kg – kilogram
LDW – Lower Duwamish Waterway
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg – milligram
ng – nanogram
PCB – polychlorinated biphenyl
RM – river mile
TEQ – toxic equivalent
TSS – total suspended solids
UCL95 – 95% upper confidence limit on the mean
USACE – U.S. Army Corps of Engineers

Table 2
Green River Input Chemistry Lines of Evidence for Benthic Risk Drivers

Chemical	Dataset	Count	Mean	Median	90th Percentile
Total HPAH (µg/kg dw)	King County Whole Water Data	19	1,320	563	4,359
	Ecology Centrifuged TSS Data	7	1,134	448	2,886
	Combined Datasets	**26**	**1,270**	**452**	**4,381**
	USACE LDW RM 4.3 to 4.75 Core Data	22	646	554	965
	Ecology Upstream Sediment Sample Data (Containing Fines >30)	72	156	39	460
	Combined Datasets	**94**	**280**	**98**	**859**
Total LPAH (µg/kg dw)	King County Whole Water Data	19	2,970	1,106	7,846
	Ecology Centrifuged TSS Data	7	130	60	315
	Combined Datasets	**26**	**2,205**	**439**	**7,218**
	USACE LDW RM 4.3 to 4.75 Core Data	22	79	69	117
	Ecology Upstream Sediment Sample Data (Containing Fines >30)	72	17	5	47
	Combined Datasets	**94**	**33**	**12**	**81**
1,4 DCB[1] (µg/kg dw)	USACE LDW RM 4.3 to 4.75 Core Data	22	0.9	0.8	2
	Ecology Upstream Sediment Sample Data (Containing Fines >30)	49	1.3	0.5	6
	Combined Datasets	**71**	**1.2**	**0.5**	**2**
BEHP[1] (µg/kg dw)	USACE LDW RM 4.3 to 4.75 Core Data	22	224	210	305
	Ecology Upstream Sediment Sample Data (Containing Fines >30)	49	75	16	232
	Combined Datasets	**71**	**121**	**20**	**260**
Mercury[1] (mg/kg dw)	USACE LDW RM 4.3 to 4.75 Core Data	22	0.18	0.09	0.12
	Ecology Upstream Sediment Sample Data (Containing Fines >30)	49	0.06	0.02	0.10
	Combined Datasets	**71**	**0.10**	**0.03**	**0.12**

Table 2
Green River Input Chemistry Lines of Evidence for Benthic Risk Drivers

Notes:

Selected as the best estimate of Green River input concentration for East Waterway Feasibility Study modeling.

1. 1,4 DCB, BEHP, and mercury were not analyzed in the King County whole water and the Ecology centrifuge studies.

µg/kg – micrograms per kilogram
BEHP – bis(2-ethylhexyl)phthalate
DCB – dichlorobenzene
dw – dry weight
Ecology – Washington State Department of Ecology
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LDW – Lower Duwamish Waterway
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
RM – river mile
TSS – total suspended solids
USACE – U.S. Army Corps of Engineers

Table 3
Preliminary Results for Recent Green River Sediment Input Concentrations - Comparison of East Waterway Box Model Inputs, King County (2016), and U.S. Geological Survey (2013-2015)

Analyte	East Waterway Box Model Inputs			King County (2016) Green River (Foster Links)				USGS (2016) Green River Progress Report Filtered Solids Golf Course at Tukwila (Data Series 880 and 973 combined)			
				Sediment Traps		Filtered Solids					
	Low	Base	High	Jar-style (mean)	Baffle-style (mean)	Baseflow (mean)	Storm (mean)	(mean)	(median)	(minimum)	(maximum)
Arsenic (mg/kg dw)	7	9	10	11	8.9	40	14	14	12	6.6	28
Total cPAHs (µg/kg TEQ dw)	40	135	270	54	45	36	160	80	48	3.7	292
Total PCBs (µg/kg dw)	5	42	80	13	5.3	7.8	30	12	4.8	0.4	84
Dioxin/furans (ng TEQ/kg dw)	2	6	8	3.0	1.9	3.5	7.1	4.8	3.1	0.5	19

Notes:
µg – microgram
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
kg – kilogram
mg – milligram
ng – nanogram
PCB – polychlorinated biphenyl
TEQ – toxic equivalent
USGS – U.S. Geological Survey

PART 4: STORM DRAIN AND COMBINED SEWER OVERFLOW CHEMISTRY DATA AND ANALYSIS FOR EW LATERAL INPUTS USED IN FS MODELING

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1 INTRODUCTION

This appendix describes the East Waterway (EW) storm drain and combined sewer overflow source chemistry data used in the different Feasibility Study (FS) modeling approaches (i.e., box model, point mixing model, and recontamination evaluation) (see Section 5.3, 5.4, and 5.5 of the FS). The process for assigning the chemical input concentrations for EW lateral inputs are described following presentation of updated source control chemical datasets from source tracing activities in storm drain (SD) and combined sewer overflow (CSO) systems that discharge to the EW.

2 NEW SOURCE DATA INCLUDED IN FEASIBILITY STUDY MODELING

The City of Seattle, King County, and the Port of Seattle conduct source-tracing sampling to identify potential contaminant sources by collecting samples of solids that accumulate within the storm drainage/combined sewer systems. Data collection is ongoing. Source tracing data, along with efforts to reduce and control contamination in these basins are discussed in Section 9 and Appendix F of the EW supplemental remedial investigation (SRI) (Windward and Anchor QEA 2014). The SRI included data collected through 2010. Since then, new data collected through 2012[1] has been incorporated in the source control dataset to be used in the FS. This section describes these new data. Only results for the key risk driver contaminants of concern (COCs) that are modeled in the FS are summarized in this section. All COCs will be considered during the design and implementation of the cleanup.

2.1 City of Seattle Source Data

The City of Seattle has collected 11 storm solids samples since 2010 for inclusion in the FS. These data include three sample types: catch basins, sediment traps, and inline solids grab samples. Table 1 lists the sample locations, sample type, and results for the COCs used in FS modeling.

[1] One sample collected by City of Seattle in January 2013 is also included. The year 2012 serves as the cutoff for development of the FS, and more recent data will be evaluated in remedial design.

Table 1

Post-Supplemental Remedial Investigation Storm Drain Solids Samples Collected by the City of Seattle included in the Feasibility Study Modeling

	Sample Name	Outfall Basin	Sample Type	Date	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Bis (2-ethylhexyl) phthalate (µg/kg dw)	1,4-Dichlorobenzene (µg/kg dw)	Total PCBs (µg/kg dw)
CB168	CB168-082012	S. Hinds St SD	CB SD	08/20/12	7 U	0.04	2,590	378	282 J	5,800 B	71 U	65 J
EWWST1	EWWST1-100912	S. Lander St SD	Trap SD	10/09/12	10	0.25	8,580	810	1,080	10,000 J	410 U	336
EWWST2	EWWST2-100912	S. Lander St SD	Trap SD	10/09/12	10	0.19	13,000	1,490	1,640 J	8,500 J	390 U	296
EWWST3	EWWST3-100912	S. Lander St SD	Trap SD	10/09/12	10 U	0.26	11,500	1,060	1,500 J	6,100 J	320 U	344
EWWST4	EWWST4-100912	S. Lander St SD	Trap SD	10/09/12	6 U	0.06	4,010	410	533	4,200 J	280 U	109 J
EWWST4	EWWST4-100912G	S. Lander St SD	Inline SD	10/09/12	20	0.07	1,140	70	154 J	620 J	54 U	22
EWWST5	EWWST5-100912	S. Lander St SD	Trap SD	10/09/12	10 U	0.11	4,180	410	578 J	9,300 J	430 U	126
EWWST6	EWWST6-100912	SPU Nearshore SD	Trap SD	10/09/12	20 U	0.31	8,630	810	1,210 J	10,000 J	850 U	210
RCB168	RCB168-010913	S. Hinds St SD	Inline SD	01/09/13	20	0.28	6,080	3,250	755	860 B	56 U	2,240
RCB251	RCB251-070512	Hanford/Lander/ Diagonal CSO[a]	RCB CS	07/05/12	10 U	0.06	1,600	265	152 J	7,700 B	120 U	103 J
RCB251	RCB251-042011	Hanford/Lander/ Diagonal CSO[a]	RCB CS	04/20/11	10 U	0.06	914 J	267 B	2 J	22,000	58 U	9,200
CB60	CB60-041012	S. Lander St SD	CB SD	04/10/12	10 U	0.11	5,360	1,450	506	46,000 B	170 U	52

Notes:
Samples were not analyzed for dioxins/furans.
µg/kg – micrograms per kilogram
A – Samples collected from catch basins within CSO basin are representative of SD inputs. The SD data from the Lander and Hanford #2 CSO basin datasets also include some samples that overlap with the Duwamish/Diagonal CSO basin inasmuch as these systems are connected.
B – analyte was found in the associated blank
CB – private on-site catch basin
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CS – combined sewer
CSO – combined sewer overflow
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
J – estimated value
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
PCB – polychlorinated biphenyl
RCB – right-of-way catch basin
SD – storm drain
SPU – Seattle Public Utilities
TEQ – toxic equivalent
U – non-detect

2.2 King County Source Data

King County has collected six solids samples from the Hanford #2 CSO Basin since 2010 for inclusion in the FS. All data were inline solids grab samples with the majority of samples being collected in the Hanford #2 CSO main trunk line. Table 2 lists the sample locations, sample type, and results for the COCs used in the FS modeling.

2.3 Port of Seattle Source Data

No new data have been collected since 2010 in the Port of Seattle storm drain basins. The Port continues to track deposition in storm drains that have been cleaned and will conduct sampling when accumulation is sufficient.

Table 2

Post-Supplemental Remedial Investigation Combined Sewer Overflow Solids Samples Collected by King County included in the Feasibility Study Modeling

	Sample Name	Outfall Basin	Sample Type	Date	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Bis (2-ethylhexyl) phthalate (µg/kg dw)	1,4-Dichlorobenzene (µg/kg dw)	Total PCBs (µg/kg dw)
A00802	L56255-1	Hanford #2 CSO	In-Line CS	8/13/2012	2.6 J	0.30	1,490 J	271	301 J	2,800	530	241 J
A00803	L56255-3	Hanford #2 CSO	In-Line CS	8/13/2012	7.5 J	0.17	1,540 J	239	298 J	2,180	170	384 J
A00805	L56255-5	Hanford #2 CSO	In-Line CS	8/13/2012	4.2 J	1.11	3,810 J	677	626 J	3,760 J	353	445
A01101	L52476-1	Hanford #2 CSO	In-Line CS	1/20/2011	6.3 J	3.91	4,840	909	698	8,250	24,900	912
A01101	L56255-7	Hanford #2 CSO	In-Line CS	8/13/2012	6 J	111 J	4,630 J	1,390	761 J	6,540	5,790	513 J
CS030	L56255-9	Hanford #2 CSO	In-Line CS	8/13/2012	7.6 J	23.2	12,100 J	3,030	3,120 J	15,400	130 U	410 J

Notes:
Samples were not analyzed for dioxins/furans.
µg/kg – micrograms per kilogram
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CS – combined sewer
CSO – combined sewer overflow
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
J – estimated value
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
PCB – polychlorinated biphenyl
TEQ – toxic equivalent
U – non-detect

3 SOURCE DATA EXCLUDED FROM FEASIBILITY STUDY MODELING

Appendix F of the SRI describes in detail the source control actions that have been implemented by the three parties (King County, City of Seattle, and Port), including line cleaning activities and provides the data that triggered the action. This section summarizes the source data that have been excluded from FS modeling due to line cleaning along with additional reasoning for removing particular data values that are not considered to be representative of the current conditions of SD and CS inputs to the EW.

3.1 Data Excluded Due to Line Cleaning

SD and CSO solids samples collected during the SRI that contained elevated levels of contaminants triggered additional source tracing and source control actions by the owners. In some cases, specific source of contaminants were identified and controlled through implementation of appropriate best management practices. Regardless of whether or not specific sources were identified, once source tracing was complete, the owners jetted and cleaned lines and/or structures that contained elevated levels of contaminants to remove accumulated sediment. Samples collected from a SD and CSO lines that were subsequently cleaned were excluded from the source tracing dataset used in the FS because the material that had accumulated in these systems over the years has been removed and no longer constitutes a potential source to the EW.[2] Line cleaning also removes historical material that could interfere with future source tracing efforts. For SD and CSO lines that have been cleaned (see Appendix F of SRI), only data collected after the cleaning have been included in the source tracing dataset used in the FS to ensure that data are representative of current rather than historical conditions. A total of 81 data points were excluded due to line cleaning and are listed in Table B4-1 of Attachment 1.

3.2 Data Excluded Due to Control of Specific Point Source

In addition to line cleaning, the control of a known point source also resulted in the exclusion of select source data from the FS modeling. Specifically, the source of

[2] These lines are typically cleaned infrequently. Therefore, material that accumulates in the lines can represent contributions from historical sources that no longer exist and may not represent post-cleaning inputs from that line.

1,4-dichlorobenzene (1,4-DCB) within the Hanford #2 CSO basin was identified and controlled. The company using the product found a substitute product that is free of 1,4-DCB; lines on the company property and the affected city-owned combined sewer lines were cleaned to the Hanford #2 CSO trunk line in January 2012 following product substitution (see Appendix F of the SRI for further details). While samples collected prior to line cleaning were excluded as discussed in Section 3.1, additional data for 1,4-DCB was excluded from the Hanford #2 Trunk Line in the overall dataset to better portray the current conditions of CSO discharges for 1,4-DCB (see Table B4-2 in Attachment 1). These excluded data represented the system prior to the cleaning and product substitution. New data collected in 2012 from these locations are used to represent current conditions. For example, samples collected in 2008-2010 from the Hanford #2 CSO trunk line were excluded for 1,4-DCB and new data for 1,4-DCB from samples collected in 2012 were used to replace these older samples.

3.3 Data Excluded Due to Other Reasons

Mercury data for one sample collected in August 2012 from Hanford #2 CSO trunk line was excluded from the source dataset for FS modeling. This sample was determined to be an outlier based on lab triplicate results. The primary sample result for Sample L56255-7 (Locator A01101) was 111 mg/kg wet weight (ww). However, the lab triplicate results were 0.48, 2.96, and 0.29 mg/kg ww, indicating the original results was an outlier and could skew the data summaries for mercury. Mercury results collected in 2011 were used for this sample location.

4 DATA AGGREGATION IN FEASIBILITY STUDY MODELING

This section summarizes the data analysis methods used for assigning chemical concentrations to EW lateral inputs for the different FS modeling approaches. The source dataset used included new data presented in Section 2 combined with the dataset presented in the SRI changed as discussed in Section 3. Data were aggregated differently for different modeling approaches. Each method is described below. Following data aggregation used for each modeling approach, the following statistics were generated and used to estimate the concentrations for the different models:

- Base case (or best estimate): Mean
- Low bounding conditions: Median
- High bounding conditions: 90th percentile

Further details regarding modeling inputs and bounding conditions are provided in Section 5 of the FS.

4.1 Box Model

A box model evaluation was used to predict the EW site-wide spatially-weighted average concentrations (SWACs) over time (years 1 through 40 following completion) for the four human health risk driver COCs (total PCBs[3], arsenic, cPAHs, and dioxin/furan). Because the model output was site-wide SWACs (not location-specific output), it was assumed that sediment deposition from upstream and lateral sources occurs evenly throughout the EW and that the net sedimentation rate is a constant value throughout the EW (Section 5.3 of the FS). The box model evaluation averages all EW lateral solids and chemistry inputs. For this reason, EW lateral sources were not assigned a different chemical concentration per outfall. Instead, the EW laterals were divided into two categories—SDs and CSOs—and separate chemistries were developed for each category. SD and CSO chemistries were not combined because some differences were noted between the discharge types. While PCBs tend to be similar on average for the discharge types, some differences were noted for PAHs, arsenic and dioxins/furans (see Table 3). Therefore, data representing CSO discharges were compiled from solids chemistry from the Hanford, Lander, and Hinds CSO service areas and data

[3] Total PCBs is also risk driver COC for fish (RAO 4).

representing stormwater discharges were combined from all storm drainage basins including the Port terminals, City of Seattle service areas, private storm drains, and catch basins draining to CSO service areas that represent stormwater only inputs to the combined sewer. Of the aggregate data, the mean, median, and 90th percentile were calculated to determine the base (or best estimate), low, and high bounding conditions, respectively. In one case (arsenic CSO concentration), the mean is lower than the median due to the distribution of the dataset. For consistency, the median was still used as the "low" estimate, and the mean was still used as the "best" estimate. In this case, the difference is only 1 mg/kg, which is within the analytical precision of the method.

Table 3
Source Tracing Datasets Summary Statistics

Chemical	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	BEHP (µg/kg dw)	1,4-DCB (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxin/Furan (ng TEQ/kg dw)
All CSOs									
Sample Count	26	24	24	24	24	24	16	26	4
Mean	5	1.71	4,000	870	680	6,700	820	260	16
Median	6	0.36	2,900	640	430	3,000	260	240	7.6
90th percentile	9	2.57	10,000	1,900	1,500	23,000	2,000	630	37
Lander CSO									
Sample Count	3	3	3	3	3	3	3	3	2
Mean	2	0.21	1,800	280	250	1,000	320	11	1.8
Median	2	0.25	2,200	220	300	800	230	11	1.8
90th percentile	2	0.26	2,700	500	380	1,700	560	18	2.6
Hanford #2 CSO									
Sample Count	22	20	20	20	20	20	12	22	2
Mean	6	2.00	3,900	890	670	7,700	990	270	30
Median	6	0.72	3,100	670	540	3,300	320	250	30
90th percentile	9	2.94	6,200	1,600	930	27,000	2,300	510	44
Hinds CSO									
Sample Count	1	1	1	1	1	1	1	1	0
Mean	9	0.43	13,500	2,400	2,100	5,400	190	850	na
Median	9	0.43	13,500	2,400	2,100	5,400	190	850	na
90th percentile	9	0.43	13,500	2,400	2,100	5,400	190	850	na
All Nearshore SD									
Sample Count	32	32	32	32	32	32	32	36	7
Mean	10	0.09	5,500	1,000	820	8,300	75	160	15
Median	10	0.08	4,400	740	550	6,200	17	39	7.9
90th percentile	15	0.14	14,000	1,900	2,100	19,000	180	440	32
S Lander SD									
Sample Count	56	56	55	55	55	55	55	58	2
Mean	9	0.15	14,000	2,600	2,100	12,000	110	120	68
Median	10	0.13	5,500	810	670	9,300	90	53	68
90th percentile	20	0.29	17,000	3,400	2,400	21,000	200	280	93
S Hinds SD									
Sample Count	6	6	6	6	6	6	6	6	0
Mean	15	0.11	3,500	1,200	350	6,300	65	560	na
Median	12	0.07	3,200	720	320	3,700	45	130	na
90th percentile	30	0.23	6,600	2,600	640	14,000	120	1,500	na
All Non-Nearshore SD									
Sample Count	99	99	98	98	98	98	97	101	2
Mean	10	0.19	10,000	2,000	1,400	19,000	140	290	68
Median	7	0.12	4,000	680	450	9,400	90	58	68
90th percentile	20	0.32	11,000	3,400	1,700	24,000	280	460	93
All SDs									
Sample Count	131	131	130	130	130	130	129	137	9
Mean	10	0.17	9,000	1,800	1,280	16,000	120	250	27
Median	9	0.10	4,000	680	480	9,10	73	55	12
90th percentile	20	0.30	13,000	3,000	1,900	22,000	270	450	53
All CSO and SD Data									
Sample Count	163	161	154	159	159	159	158	168	13
Mean	9	0.40	8,200	1,600	1,200	14,000	1,200	300	23
Median	7	0.12	3,800	650	440	7,100	90	64	12
90th percentile	20	0.67	12,300	2,400	1,800	22,000	570	520	46

Notes:
µg/kg – micrograms per kilogram
1,4-DCB – 1,4-dichlorobenzene
BEHP – bis(2-ethylhexyl)phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
na – not applicable
ng/kg – nanograms per kilogram
PCBs – polychlorinated biphenyls
SD – storm drain
TEQ – toxic equivalent

4.2 Point Mixing Model and Recontamination Evaluation

The point mixing model and the recontamination evaluation applied chemistry concentrations for lateral loads to a finer resolution than the box model. The point mixing model is the method used in the FS to assess MNR performance for RAO 3. Specifically, it is used to predict location specific EW surface sediment concentrations over time for the key benthic risk driver COCs where MNR is the remedial technology (see FS Section 5.5 for a description of the point mixing model and FS Section 9 for the results). The recontamination evaluation is the method used in the FS to identify areas within the EW that have the potential to recontaminate over time (see FS Section 5.4 for a description of the model and FS Appendix J for a presentation of the results). Both evaluations used the results of numerical modeling (i.e., the PTM) as an input to a GIS-based grid model[4] to estimate deposited sediment concentrations post-remediation for nine key risk driver COCs (Section 5.4 of the FS and Appendix J).

Since the point mixing model and recontamination evaluation calculates surface concentrations based on a model cell-by-cell basis based on initial deposition patterns predicted by the PTM output, it was necessary to break down EW lateral sources into finer resolution for chemistry assumptions. Using individual results for each basin was not possible because data were not available to adequately characterize each individual basin. For example, often a basin only had one result or no results so assignment of chemistry could not be made in this approach. In other cases, lines throughout a basin had been cleaned and either no samples or only one sample were available since the line cleaning. Therefore, chemistry assumptions applied to the PTM solids output for the point mixing model and the recontamination potential evaluation were assigned based on the following six basin-type categories:

- Hinds CSO
- Lander CSO
- Hanford #2 CSO
- Nearshore SDs (storm drains serving Port terminals and other similar areas)
- Non-nearshore SDs (storm drains serving other non-terminal areas like bridges,

[4] The grid model divides the EW into contiguous square cells with a 50-foot x 50-foot resolution for use in the recontamination evaluation (grid model evaluation).

roadways, and other upland properties, including private storm drain systems)
- S Lander St SD.

Source data were aggregated based on similarities in outfall types/basin land uses rather than assigning data for each individual outfall. The rationale for this is summarized below.

4.2.1 CSO Chemistry Data Assignments

Data as amended in Section 3 for each CSO basin were summarized and reviewed as mean, median and 90th percentile data summaries (see Table 3). Source tracing data results for each basin and number of samples were considered when deciding how to assign chemistry for each CSO. Solids source tracing data collected from Lander CSO basin showed much lower concentrations of most contaminants then Hanford #2 CSO basin. Therefore, it was not appropriate to include samples collected in Hanford #2 CSO basin with the Lander CSO basin and thus, the source datasets were used independently to assign chemistry for each basin. The Hinds CSO basin, which is much smaller than the other two CSO basins, had only one sample available. Because of the limited data for this basin, data for all CSO combined (same as that used for the box model) was assigned to Hinds CSO. This may overestimate or underestimate (depending on the contaminant) the contaminant concentrations being discharged from Hinds CSO.

4.2.2 Storm Drain Chemistry Data Assignments

Data as amended in Section 3 for each SD basin of similar land uses, size, or categories were summarized and reviewed as mean, median and 90th percentile data summaries (see Table 3). Source tracing data results for each similar basin and number of samples per basin were considered when deciding how to assign chemistry for SD outfalls.

Data for samples collected from storm drains serving Port terminals and other similar areas were combined into the nearshore SD category. These include the SW Florida St SD (B-21), B-25, all Port SDs, and all private SDs along waterfront (A-6, B-40, B-41, B-42, B-43) (see Figure 2 in Appendix B, Part 1). These nearshore SDs have similar land use and there were not enough samples collected from individual drainage systems to support calculating separate chemistry inputs for the PTM. All nearshore SD concentrations were assumed equal and aggregated because of: 1) the limited sampling; and 2) post-sampling line cleaning, which would change measured concentrations. Summaries were developed for the aggregated dataset. This may overestimate or underestimate (depending on the contaminant) of the contaminant concentrations being discharged from an individual basin.

Data for samples collected from storm drains serving roadways, bridges, and upland industrial properties other than Port terminals (e.g., U.S. Coast Guard and Olympic Tug and Barge) were combined into the non-nearshore SDs category which includes the S Hinds St SD, SW Spokane St emergency overflow/SD (B-5), SW Spokane St SD (B-4), S Spokane St SD (B-36), and all bridges (BR-2, BR-4, BR-34, BR-39). With the exception of the S Hinds St SD (39.5 acres), these outfalls serve small drainage areas (<1 - 13 acres) and none had sufficient samples to support calculating separate chemistry inputs for the PTM. Because the land use in these basins is significantly different from nearshore SDs, the solids chemistry inputs were calculated separately from the nearshore SDs. S Hinds St SD data were combined with the non-nearshore SDs because only one inline sample has been collected after cleaning (RCB168) and data for the private on-site catch basins in the S Hinds St SD (CB59, CB134, CB135, CB168) were not considered representative of the solids discharges from this outfall because catch basins collect runoff from a fairly small catchment area (less than 1 ac) and may not be representative of the basin as a whole.

The S Lander St storm drain was handled separately for the PTM, because this system is unique in that it serves a much larger (442 acres) and diverse drainage basin than the other non-nearshore SDs. Existing data were also sufficiently robust (59 samples) to characterize the solids chemistry in this basin.

5 CURRENT AND FUTURE EAST WATERWAY LATERAL CONDITIONS

The box model, point mixing model and recontamination evaluation all included an analysis of both current and potential future source control conditions for EW laterals. Current conditions for modeling purposes were defined as now through 10 years post-construction of the remedy, and future conditions were defined as 10 years and beyond post-construction of the remedy. This was to acknowledge the uncertainty in the timing of known future source controls. Current and potential future conditions chemistry assumptions were developed for EW laterals (i.e., SDs and CSOs). The current chemistry conditions are based on the data analysis discussed thus far in this appendix (e.g., consideration of current source control actions). Chemistry values for potential future conditions differed compared to current conditions for some COCs for SDs based on likely future source control efforts. The following summarizes how future chemistry conditions were treated for CSOs and SDs.

5.1 Future Conditions (CSOs)

Changes in chemistry were not assumed for CSO basins for the following reasons:

- **Hinds CSO.** The City currently plans to control overflows from the Hinds CSO through a system retrofit that should not substantially change the discharge composition and therefore no changes in chemistry are assumed at this stage. Rather the discharge volume will be reduced to on average one uncontrolled event per year as required under the City's National Pollutant Discharge Elimination System (NPDES) permit.[5]
- **Hanford #2 and Lander CSOs.** The current CSO control plan by King County is to install a wet weather treatment plant to control overflows from these two CSOs. Because most treatment technologies function by removing solids rather than removing chemicals from the solids, the modeling included a reduction in solids but did not assume any change in chemistry on the solids remaining after treatment. Treatment could result in some reductions in chemistry but none were estimated for

[5] For the PTM, it was assumed that annual discharge volumes would be reduced from approximately 1 to 0.6 million gallons per year. The City has not completed modeling the Hinds CSO system. Therefore, reductions in overflow volumes were conservatively estimated. Available information suggests that approximately 5 overflows currently occur per year.

the FS modeling[6]. By assuming no change in chemistry, the analysis should provide a conservative estimate for CSOs following treatment. Note there remains on average one untreated event per year at these outfalls in addition to the treated flows. These untreated flows also did not assume any change in chemistry.

5.2 Future Conditions (Port-owned Storm Drains)

Changes in chemistry were not assumed for Port-owned SD basins because changes in chemistry could not be predicted based on additional source control actions. The FS instead assumed that the stormwater treatment to be installed by the tenants as required under their NPDES industrial stormwater permits is expected to reduce solids load from these basins. Most stormwater treatment technologies function by removing solids present in stormwater, but and are not effective removing the contaminants adsorbed to the solids. Therefore, the modeling assumed a reduction in solids concentrations and did not assume any change in chemistry on the solids remaining after treatment. While treatment could potentially result in reductions in chemistry, none were assumed for the FS modeling.

5.3 Future Conditions (City-owned Storm Drains)

For the City-owned storm drains, future lateral inputs were estimated by adjusting the solids chemistry concentrations to reflect improvements that are expected to occur as a result of ongoing source control efforts in the EW drainage basin. To simulate lateral inputs after the implementation of source control measures, the source tracing dataset for City-owned storm drains was screened by replacing all values above a set replacement concentration with the replacement concentration (see Table 4). This approach assumes that the existing source(s) are not entirely eliminated, but are reduced via source control actions. For arsenic and mercury, the replacement concentrations were selected based on the screening levels currently used to screen for and trace sources (i.e., CSL or the Second Lowest Apparent Effects Threshold [2LAET] dry weight equivalent). For LPAH, HPAH, BEHP, PCBs, and 1,4-DCB, higher concentrations were used because these chemicals have been shown to be harder to control in urban settings. For these chemicals, the replacement values were set

[6] Reductions in source inputs from CSO treatment were accounted for through removal of solids (and particle-associated chemistry) and changes to particle sizes of solids discharged (see Appendix B, Part 1).

based on the distribution of concentrations in the source tracing dataset and best professional judgment regarding the likely impact of source control efforts.

Following replacement, mean, median, and 90th percentile concentrations were recalculated from the dataset and used as the best estimate, low, and high estimated lateral loads, respectively (see FS Table 5-7).

Table 4
Replacement Values to Approximate Results of Future Source Control Actions in City Storm Drains

	Arsenic (mg/kg dw)	**Mercury (mg/kg dw)**	**Total LPAHs (µg/kg dw)**	**Total HPAH (µg /kg dw)**	**BEHP (µg /kg dw)**	**Total PCBs (µg /kg dw)**	**1,4-DCB (µg /kg dw)**
CSL/2LAET	93	0.59	5,000	17,000	1,900	1,000	110
Replacement Concentration[a]	**93**	**0.59**	**15,000**	**50,000**	**100,000**	**2,000**	**1,000**
Samples modified	None	CB16-020904 CB26-031504 CB30-043004 CB30-091610	CB26-031504 CB54-020905	CB26-031504 CB151-111209	CB27B-081210 CB30-091610	RCB251-042011 CB22-030204 RCB168-010913	CB22-030204

Notes:
CSL/2LAET shown for reference.
a. The concentration that was substituted for all values exceeding this value.
µg/kg – micrograms per kilogram
1,4-DCB – 1,4-dichlorobenzene
2LAET – Second Lowest Apparent Effects Threshold
BEHP – bis(2-ethylhexyl)phthalate
CSL – Cleanup Screening Level
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
PCB – polychlorinated biphenyl

6 REFERENCE

Windward and Anchor QEA, 2014. Supplemental Remedial Investigation. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Final. January 2014.

ATTACHMENT 1
SAMPLES REMOVED FROM FS DATASET DUE TO LINE CLEANING AND SOURCE CONTROL

Table B4-1
Storm/CSO Solids Samples Removed from FS Dataset due to Line Cleaning

Location Name	Sample Name	Outfall Basin	Sample Type	Date	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Bis (2-ethylhexyl) phthalate (µg/kg dw)	1,4-Dichlorobenzene (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxins/furans TEQ (ng TEQ/kg dw)
CB133	CB133-012009	S Hinds St SD	SD CB	01/20/09	6 UJ	0.04 U	19 U	19 U	17	26	19 U	20 U	
MH113	MH113-050310	S Hinds St SD	SD Inline	05/03/10	20	0.7	5,000 J	1,680	330 J	9,000	270 U	260	81.9
RCB138	RCB138-050108	S Hinds St SD	SD Inline	05/01/08	20	0.69	1,460 J	659 J	139 J	1,200	99 U	1,140	
MH109	MH109-111209	S Hinds St SD	SD Inline	11/12/09	14.4	0.52 J	10,500 J	1,540 J	1,580 J	3,800	60 U	208	
MH107	MH107-111209	S Hinds St SD	SD Inline	11/12/09	10	0.16 J	11,005 J	2,490 J	1,170 U	47,000	300 U	705	
RCB168	RCB168-041009	S Hinds St SD	SD Inline	04/10/09	10 U	0.04	148 J	28	24 J	290	20 U	20 U	
MH104	MH104-072709	S Hinds St SD	SD Inline	07/27/09	7	0.12	9,250 J	2,410	897 J	3,200	57 J	60	
RCB46	RCB46-082405	S Hinds St SD	SD RCB	08/24/05	10 U	0.05 U	2,340	350	297	3,000 B	120 U	250	
MH114	MH114-050610	Hanford #2 CSO	CS Inline	05/06/10	80	6.6	38,240 J	8,250	5,220 J	1,500 J	57 J	41,300	
MH115	MH115-052510	Hanford #2 CSO	CS Inline	05/25/10	32	9.2	18,600	4,640 J	2,400	1,400	100 U	1,470	
RCB135	RCB135-031408	Nearshore SD	SD Inline	03/14/08	12.7	0.3	8,040 J	1,300	1,020 J	33,000	1,000 U	285	
MH133	MH133-050310	SW Spokane St SD, B-4	SD Inline	05/03/10	10	0.17	11,400 J	1,810 J	972 J	33,000	230 U	284	34.6
RCB133	RCB133-031408	SW Spokane St SD, B-4	SD Inline	03/14/08	12.3	0.35	10,800 J	1,450	1,240 J	45,000	1,200 U	376	
CB19	CB19-021204	Hanford/Lander/ Diag CSO	CS CB	02/12/04	25	1.82	9,620 J	3,200	1,210 J	53,000	1,200 U	289	
CB27B	CB27-032604	Hanford/Lander/ Diag CSO	CS CB	03/26/04	20 U	0.1 U	18,900	2,800 U	2,760	140,000	2,800 U	68 J	
CB60	CB60-031705	S Lander St SD	SD CB	03/17/05	11	0.08	9,200	7,300	1,640	160,000	1,800 U	320 Y	
CB65	CB65-032205	Port SD, B-11	SD CB	03/22/05	10	0.27	3,030 J	420	289 J	19,000	140 U	2,110	25.6 J
CB65	CB65-112910	Port SD, B-11	SD CB	01/29/10	7.7	0.23	3,060 J	420	666 J	36,000	230 U	3,000	
A00709	L49290-1	Hanford #2 CSO*	CS Inline	10/13/2009								347,000 J	
A00929	L49290-2	Hanford #2 CSO*	CS Inline	10/13/2009								178,000	
A00818	L49290-4	Hanford #2 CSO	CS Inline	10/14/2009	6.93 J	0.77	51,400	9,900	8,080	6,890	88 J	1,640	
A00817	L48945-4	Hanford #2 CSO	CS Inline	9/1/2009	6 J	2.3 J	1,440	179	204	2,370	1,370,000	152 J	
A00817	L50935-7	Hanford #2 CSO	CS Inline	9/1/2009									
A00817	L50935-8	Hanford #2 CSO	CS Inline	9/1/2009									
A00903	L48945-11	Hanford #2 CSO	CS Inline	9/2/2009	7.8 U	0.33 J	1,680	611	299	5,220	44,500,000		
A00904	L48945-9	Hanford #2 CSO	CS Inline	9/2/2009			3,830	1,100	507	4,380	2,680,000		
A00904	L50498-6	Hanford #2 CSO	CS Inline	9/2/2009	19	6.40 J						1,100	
A00904	L50935-25	Hanford #2 CSO	CS Inline	9/2/2009									
A00904	L50935-26	Hanford #2 CSO	CS Inline	9/2/2009									
A00918	L48945-7	Hanford #2 CSO	CS Inline	9/1/2009	9.73	16.7	17,300	5,700	2,150	996	390	12,100 J	
A00918	L48945-8	Hanford #2 CSO	CS Inline	9/1/2009	12.3		22,000	6,220	2,840	1,310	56	36,700 J	

Table B4-1
Storm/CSO Solids Samples Removed from FS Dataset due to Line Cleaning

Location Name	Sample Name	Outfall Basin	Sample Type	Date	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Bis (2-ethylhexyl) phthalate (µg/kg dw)	1,4-Dichlorobenzene (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxins/furans TEQ (ng TEQ/kg dw)
A00918	L50935-11	Hanford #2 CSO	CS Inline	9/2/2009		4.83 J							
A00918	L50935-12	Hanford #2 CSO	CS Inline	9/2/2009									
A00918	L50935-13	Hanford #2 CSO	CS Inline	9/2/2009									
A00918	L50935-14	Hanford #2 CSO	CS Inline	9/2/2009									
A01010	L51483-3	Hanford #2 CSO	CS Inline	8/10/2010	3.6 J	0.30 J							
A01010	L51483-4	Hanford #2 CSO	CS Inline	8/10/2010									
EW08-B7-CB01	EW08-B7-CB01	Port SD, B-7	SD CB	12/7/2008			14,500 J	4,800	1,180 J	21,000 J	6 U		
EW08-B7-CB02	EW08-B7-CB02	Port SD, B-7	SD CB	12/7/2008			6,200 J	1,130	686 J	13,000	12 U		
EW08-B7-CB03	EW08-B7-CB03	Port SD, B-7	SD CB	12/7/2008			10,400 J	1,900 J	947 J	17,000	7 U		
EW08-B7-CB04	EW08-B7-CB04	Port SD, B-7	SD CB	12/7/2008			6,200 J	1,120 J	576 J	39,000	6 U		
EW08-B7-CB05	EW08-B7-CB05	Port SD, B-7	SD CB	12/7/2008			16,200 J	2,300	1,850 J	11,000	6 U		
EW08-B7-CB06	EW08-B7-CB06	Port SD, B-7	SD CB	12/7/2008			10,200 J	4,200	335 J	75,000	58 U		
EW08-B7-CB-COMP01	EW08-B7-CB-COMP01	Port SD, B-7	SD CB	12/7/2008	8 U	0.1	17,300 J	4,500 J	1,550 J	39,000 J	59 U	54	
EWWST7-040110-comp	EWWST7-040110-comp	Port SD, B11	SD Inline	4/1/2010									82.4
EW10-B11-MH01	EW10-B11-MH01	Port SD, B-11	SD Inline	3/31/2010								7,200 J	
EW10-B11-MH02	EW10-B11-MH02	Port SD, B-11	SD Inline	3/31/2010								320	
EW10-B11-MH03	EW10-B11-MH03	Port SD, B-11	SD Inline	3/31/2010								86,000	
EW10-B11-MH08	EW10-B11-MH08	Port SD, B-11	SD Inline	3/31/2010								860	
EW10-B11-MH09	EW10-B11-MH09	Port SD, B-11	SD Inline	3/31/2010								1,040	
EWWST7	EWWST7-032709	Port SD, B-11	SD Trap	3/27/2009								240	
	EWWST7-032709G	Port SD, B-11	SD Inline	3/27/2009	20	0.2	1,590	150	245	2,300	150 U	530	
	EWWST7-040110	Port SD, B-11	SD Trap	4/1/2010	20	0.18	10,900 J	860	1,210 J	24,000	330 U	740	
	EWWST7-040110G	Port SD, B-11	SD Inline	4/1/2010	30	0.32	7,900	610 J	894	17,000	160 U	1,800	
	EWWST7-111708G	Port SD, B-11	SD Inline	11/17/2008	20 U	0.37 J	3,510	430	503	6,600	61 U	780	
EW10-B37-MH01	EW10-B37-MH01	Port SD, B-37	SD inline	4/20/2010	30 U	0.45	12,100	4,400	1,410	10,000	34 U	180	80.8 J
EW10-B34-MH01	EW10-B34-MH01	Port SD, B34	SD inline	4/20/2010	88	1.27	8,000 J	470	1,020 J	3,600	30	10,100	784 J
EW08-B32-CB01	EW08-B32-CB01	Port SD, B32	SD CB	12/9/2008	20 U	0.6						660 J	
EW08-B32-CB02	EW08-B32-CB02	Port SD, B32	SD CB	12/9/2008	16	0.06 U						59 J	
EW08-B32-CB03	EW08-B32-CB03	Port SD, B32	SD CB	12/9/2008	8	0.08						20 U	
EW08-B32-CB04	EW08-B32-CB04	Port SD, B32	SD CB	12/9/2008	20 U	0.09						20 U	
EW08-B32-CB05	EW08-B32-CB05	Port SD, B32	SD CB	12/9/2008	13	12.7						670 J	

Table B4-1
Storm/CSO Solids Samples Removed from FS Dataset due to Line Cleaning

Location Name	Sample Name	Outfall Basin	Sample Type	Date	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Bis (2-ethylhexyl) phthalate (µg/kg dw)	1,4-Dichlorobenzene (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxins/furans TEQ (ng TEQ/kg dw)
EW08-B32-CB06	EW08-B32-CB06	Port SD, B32	SD CB	12/9/2008	9 U	0.18						310 J	
EW08-B32-CB-COMP01	EW08-B32-CB-COMP01	Port SD, B32	SD CB	12/9/2008	20 U	2.57	6,500	1,320 J	914	14,000	63 U	153	
EW08-B24-CB-COMP01	EW08-B24-CB-COMP01	Port SD, B24	SD CB	12/7/2008	7 U	0.08 U	6,400 J	1,600 J	811 J	11,000	48 U	39	
EW10-B7-MH01	EW10-B7-MH01	Port SD, B7	SD Inline	4/22/2010	10	0.03	1,350 J	170 J	120 J	980	6 U	40	
EW10-B24-MH01	EW10-B24-MH01	Port SD, B24	SD Inline	4/22/2010	31	0.44	2,880 J	300 J	423 J	3,100	7	1,200	
EW10-B32-MH01	EW10-B32-MH01	Port SD, B32	SD inline	4/20/2010	20	0.04	2,100 J	410 J	209 J	5,200	18 U	93	
EW10-MH-comp1	EW10-MH-comp1	Port SD, B1, B37	SD Inline	4/20/2010									110 J
EW10-B1-MH01	EW10-B1-MH01	Port SD, B1	SD Inline	4/22/2010	15	0.13	8,600 J	2,800	667 J	11,000	6 U	260	148 J
EW10-B16-MH01	EW10-B16-MH01	Port SD, B16	SD Inline	4/22/2010	30	0.26	4,110 J	380 J	233 J	2,000	6 U	2,800	44.5
CB27b	CB27B-081210	Hanford/Lander/ Diag CSO	CS CB	08/12/10	5	0.1 U	20,900 J	2,400	2,560 J	1,400,000 B	2,100 U	330	
CB141	CB141-050409	Port SD, B37	SD CB	05/04/09	10 U	0.39 J	9,910 J	3,310 J	752 J	16,000	330 U	131 J	
CB68	CB68-042805	Port SD, B7	SD CB	04/28/05	10 U	0.1 U	440 J	330	163	8,800	180 U	67	
CB71	CB71-052505	Port SD, B16	SD CB	05/25/05	8	0.07	1,830	400	218	5,300	220 U	58 J	
CB66	CB66-032505	Port SD, B37	SD CB	03/25/05	13	0.28	7,010 J	3,740 J	1,030 J	22,000	1,100 U	140 Y	
CB65	CB65-032205	Port SD, B11	SD CB	03/22/05	10	0.27	3,030 J	420	289 J	19,000	140 U	2,110	25.6 J
CB65	CB65-112910	Port SD, B11	SD CB	01/29/10	7.7	0.23	3,060 J	420	666 J	36,000	230 U	3,000	
CB60	CB60-041012	Lander SD	SD CB	04/10/12	10 U	0.11	5,360	1,450	506	46,000 B	170 U	52	
CB22	CB22-030204	Hanford/Lander/ Diag CSO	CS CB	03/02/04	20 U	0.16	39 U	39 U	35 U	410	520,000	3,200	
CB19	CB19-070910	Hanford/Lander/ Diag CSO	CS CB	07/09/10	10 U	0.31	2,285 J	305 J	199 J	30,000	160 U	210 J	
CB124	CB124-082908	Port SD, B37	SD CB	08/29/08	9	0.17	6,410	17,900 J	748	60,000	770 U	120	

Notes:
* Sampled from private lines on Rainier Commons
µg/kg – micrograms per kilogram
BEHP – bis(2-ethylhexyl)phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
FS – Feasibility Study
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
J – estimated value
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
ng/kg – nanograms per kilogram
PCB – polychlorinated biphenyl
SD – storm drain
TEQ – toxic equivalent
U – non-detect

Table B4-2
CSO Solids Samples Removed from FS Dataset due to Source Control of 1,4-Dichlorobenzene

Location Name	Sample Name	Outfall Basin	Sample Type	Date	1,4-Dichlorobenzene (µg/kg dw)
A00802	L48945-6	Hanford #2 CSO	Inline CS	9/1/2009	52,900
A00803	L48945-5	Hanford #2 CSO	Inline CS	9/1/2009	547
A00805	L48945-1	Hanford #2 CSO	Inline CS	9/1/2009	8,070
A00805	L48945-2	Hanford #2 CSO	Inline CS	9/1/2009	9,090
A01101	L52476-1	Hanford #2 CSO	Inline CS	1/20/2011	24,900
ST805-L1-1	L50498-1	Hanford #2 CSO	Trap CS	4/23/2009	628
ST805-L1-3	L50498-3	Hanford #2 CSO	Trap CS	2/19/2010	60,900
ST805-L2-1	L50498-4	Hanford #2 CSO	Trap CS	2/19/2010	3,680

Notes:
All other data analyzed were retained. Only 1,4-dichlorobenzene was removed as discussed in Section 3.2.
µg/kg – micrograms per kilogram
CS – combined sewer
CSO – combined sewer overflow
dw – dry weight
FS – Feasibility Study

PART 5: CONSIDERATIONS FOR MANAGEMENT OF DREDGING RESIDUALS

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LIST OF ACRONYMS AND ABBREVIATIONS

μg/kg	microgram per kilogram
BAZ	biologically active zone
BMP	best management practices
COC	contaminant of concern
dw	dry weight
ENR	enhanced natural recovery
EW	East Waterway
FS	Feasibility Study
MNR	monitored natural recovery
NRC	U.S. National Research Council
PCB	polychlorinated biphenyl
RAL	remedial action level
RMC	residuals management cover
SWAC	spatially-weighted average concentration
TOC	total organic carbon
USACE	U.S. Army Corps of Engineers

1 INTRODUCTION

This appendix provides a summary of considerations related to the management of dredging residuals generated during dredging activities proposed in East Waterway (EW) Feasibility Study (FS) remedial alternatives. The generation of dredging residuals is inherent to the dredging process, due to the loss and re-deposition of sediment during each dredging pass. Generated dredging residuals can result in elevated surface sediment contaminants of concern (COC) concentrations and associated risks that exceed the project performance goals. Therefore, dredging best management practices (BMPs) will be needed to meet risk-based performance goals following remediation. During remedial design, an adaptive residuals management decision framework will be developed that will specify triggers (e.g., post-dredging concentrations), and resulting residuals management measures (e.g., the placement of residuals management cover [RMC]) that will be implemented as part of dredging.

This appendix summarizes the state of knowledge of dredging residuals, including a description of the processes that generate residuals and residuals management approaches that have been used at other dredging sites (Section 2). Additionally, this appendix summarizes and compares dredging BMPs and contingency measures that are likely to be part of the residuals management decision framework developed in design (Section 3). Finally, this appendix summarizes the common assumptions selected for residuals management for modeling and costing the FS alternatives (Section 4).

2 DREDGING RESIDUALS

Meeting remedial objectives for a contaminated sediment remediation program is often defined by the level of contamination remaining in the surficial sediments after the remediation effort, rather than by the mass of contaminants removed. Reliable characterization and an accurate dredging prism design are key elements to the success of a remediation effort; however, complete removal of contaminated sediments within an aquatic environment is limited by the technical and logistical limitations of the environmental dredging equipment and methods, and the characteristics of the aquatic environment.

2.1 Types of Dredging Residuals

Residuals are grouped into two categories: 1) undisturbed residuals, also referred to as "missed inventory"; and 2) generated residuals (Figure 2-1).

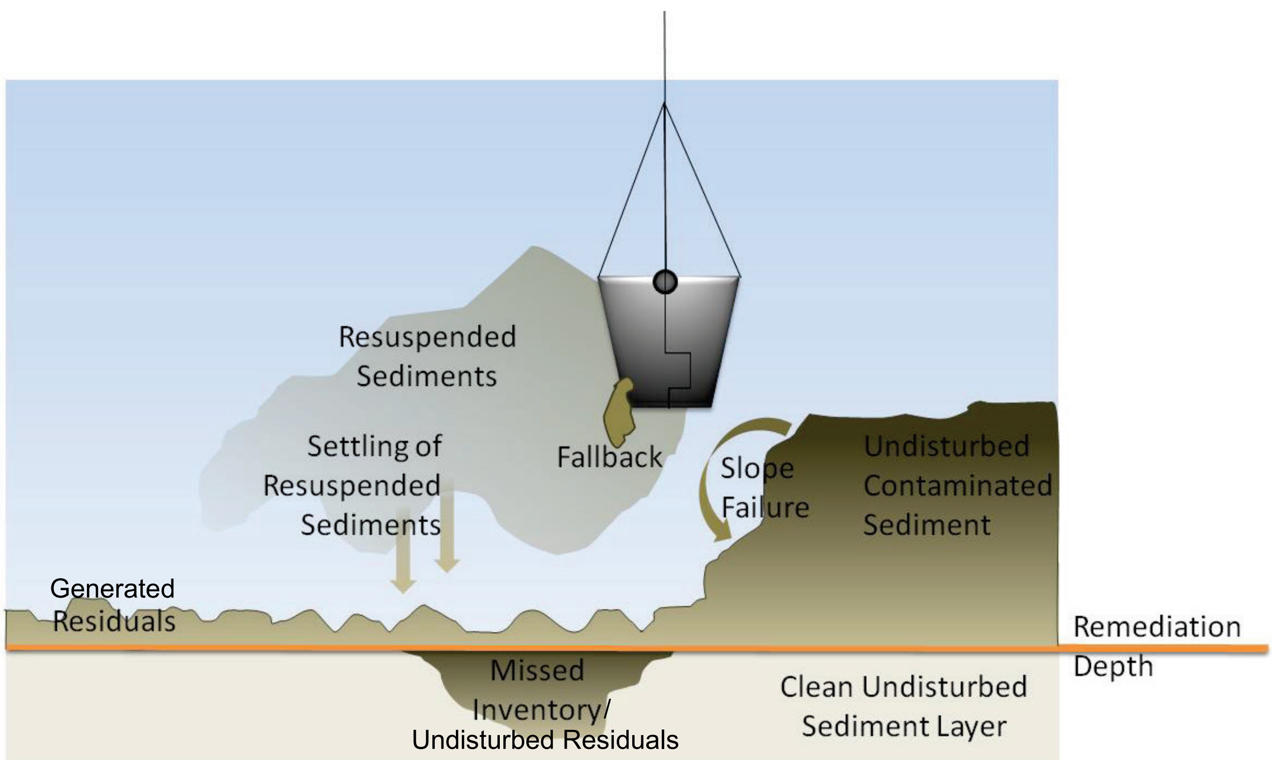

Figure 2-1

Residuals from Sediment Remediation Processes with Mechanical Dredging

Undisturbed residuals refers to contaminated sediments that have been uncovered but not removed. The primary causes of undisturbed residuals are: 1) incomplete characterization, resulting in inaccurate remediation designs (missed inventory); and 2) incomplete dredging due to technical and logistical limitations (e.g., structural setbacks). In an effort to minimize the potential for undisturbed residuals, lateral and vertical characterization of chemical and geotechnical gradients will be completed during remedial design for the EW. Although a certain amount of undisturbed residuals is anticipated due to technological limitations of dredging equipment, geotechnical and structural stability, and limitations in contaminant characterization, this memorandum focuses on generated dredge residuals and associated BMPs. Addressing undisturbed residuals is important for achieving dredging goals, and undisturbed residuals will be investigated during post-dredge sampling and addressed as part of contingency actions.

Generated dredge residuals are a byproduct of all dredging operations and result from the physical processes of moving sediment underwater with large equipment. Both hydraulic and mechanical dredging activities generate residuals, although this memorandum focuses on mechanical dredging methods that are anticipated to be used in the EW. In general, mechanical dredging is expected to control residuals better than hydraulic dredging in sediments containing debris, loose rock, or vegetation (USACE 2008a).

The U.S. Army Corps of Engineers (USACE; 2008a) describes the physical processes of the different types of mechanical dredges and the associated generated residuals (Figure 2-1 depicts the generation of residuals during mechanical dredging). Sediments are inherently mobilized during the dredging process; they are resuspended in the water column as the dredging bucket penetrates the sediment surface, and as clumps of sediment fall from the equipment as it moves across the sediment or through the water. The degree of disturbance is dependent on the conditions of the site (e.g., slope, current, structures, and presence of bedrock and debris), the type of bucket, and operator performance (e.g., speed, overfilling, or over-penetration of the bucket). Incomplete closure of the bucket from debris and rocks will result in sediment leaking from the bucket. Additionally, during dredging some amount of fallback, sloughing, or sediment slope failure following a dredge cut is also to be expected. After dredging, a new surficial sediment layer is formed from the accumulation of disturbed sediments and the settling of resuspended sediments, referred to as the generated dredging residuals layer.

2.2 Relevant Studies and Guidance

Multiple case study documents and guidance documents related to the management of dredging residuals have been published in the past decade. These documents discuss how to estimate the quantity of dredging residuals, dredging operational factors and site conditions that affect the generation of residuals, and approaches to adaptively manage residuals following dredging through monitoring and contingency actions.

The U.S. Environmental Protection Agency regards post-dredging residuals as a high research priority in its Superfund program (EPA 2009). The USACE Engineering and Research Development Center led scientific workgroup meetings and subsequent publications focusing on post-dredging residuals. This scientific workgroup contributed to multiple peer-review publications and scientific conferences, and two USACE guidance documents: *The Four Rs of Environmental Dredging: Resuspension, Release, Residual, and Risk* (USACE 2008b) and *Technical Guidelines for Environmental Dredging of Contaminated Sediments* (USACE 2008a). In addition to efforts led by USACE, the U.S. National Research Council (NRC) Committee on Sediment Dredging at Superfund Megasites developed the *Sediment Dredging at Superfund Megasites: Assessing the Effectiveness* report in 2007 (NRC 2007), which focuses particular attention on the assessment and management of post-dredging residuals.

2.2.1 Estimating Generated Residuals

A key source of case study information is Patmont and Palermo (2007), which summarized case histories and calculated the amount of generated residuals relative to the mass of contaminant dredged for multiple projects. This work was subsequently updated by Desrosiers and Patmont (2009) and Patmont, LaRosa, and Narayanan (2015). These studies have examined more than 50 sediment remediation programs with post-dredge residuals data to assess dredging effectiveness and residuals generation estimates. These documents developed the methods used for estimating dredging residuals used in this FS (see also FS Appendix B, Part 3A). They identified more than 15 environmental dredging projects that had relatively robust pre- and post-dredge datasets, enabling reliable mass-balance calculations to estimate the loss of sediment during dredging. These sites represent different areas of North America, various types and concentrations of COCs, and a range of project sizes and dredging methodologies. Patmont and Palermo (2007) and Desrosiers and Patmont

(2009) then developed bounding-level estimates of residuals using a mass-balance approach by comparing pre-dredge data to post-dredge data. They summarize the factors that impact generation of residuals as follows:

- Contaminant concentrations in residuals approximate the average concentration of COCs in dredged material.
- Generated residuals represent the majority of residuals contaminant mass, while undisturbed residuals contributed a minor amount of contaminant mass.
- Generated residuals range from 1% to 11% and averaged 5% of the mass that was present in the last dredge cut.

2.2.2 Operational Factors and Site Conditions that Affect Generated Residuals

Operational factors and site conditions that affect residuals were discussed in a number of the documents reviewed for this summary. Patmont and Palermo (2007) found that the average dry density of the sediments and the presence of debris and/or bedrock or hardpan were two important factors impacting the mass of contaminants in the residuals layer. Low solids content and the presence of more debris, bedrock, or hardpan contribute to higher generated residuals. NRC (2007) also describes that the magnitude of residuals can be higher in the presence of debris or when site conditions make it infeasible to overdredge into clean material. Cieniawski et al. (2009) found that low residuals concentrations were achievable in an area with extensive bedrock only through extensive re-dredging using specialized hydraulic dredging equipment.

Fuglevand and Webb (2009) highlight the equipment and operational factors that influence residuals, including equipment selection, size of the dredge bucket or cutter head, the accuracy of positioning, and the overlap of dredge bucket cuts. Additional operational factors discussed in these documents include number of dredge passes, selection of intermediate and final cutline elevations, allowable overdredging, dredging production rates, slopes and sloughing, experience of operator, and sequence of operations.

2.2.3 Residuals Management Decision Frameworks and Contingency Measures

A primary focus of case study and guidance documents is the adaptive management decision framework and contingency measures that can be implemented to manage dredging residuals. USACE (2008b) summarizes potential residuals management contingency actions as follows:

> *Generated residuals and undisturbed residuals should be managed based on an operational evaluation of what can practically be done (i.e., cost benefit analysis). Management options include:*
>
> - *Operational controls to reduce residuals as a part of operations*
> - *If cleanup levels are not met – possible management options include:*
>   - *Monitored natural recovery – consider burial and mixing*
>   - *Residual covers (e.g., 6 in. of sand or topsoil) – long-term intention may be sediment dilution, but can also be designed and constructed as necessary to provide an isolation component*
>   - *Engineered caps – intention is physical and chemical isolation*
>   - *Re-dredging (if practicable; re-dredging will likely be less effective for generated residuals, but may be a reasonable management option if significant thicknesses of undisturbed residuals are present)*

USACE (2008a) emphasizes that the nature and extent of residuals and site conditions should determine residuals management actions used following dredging. NRC (2007) reviewed a number of case studies of environmental dredging and highlight the use of placing a RMC to manage residuals as follows:

> *Generally, control of residuals is achieved by adding backfill or thin-layer capping; this has clear advantages in achieving bulk sediment contaminant concentration targets even if the backfill layer is intermixed with the residual sediments.*

Patmont and Palermo (2007) reached a similar conclusion regarding the use of residuals management methods as follows:

> *Performance requirements for multiple passes of the dredge to achieve a very low residual concentration have often been inefficient and costly, with little or no discernable benefit in the form of reduced generated residual concentrations or thicknesses. Placement of a residual cover or cap of clean material has provided greater certainty in achieving residual performance standards at the case study project sites.*

Other studies summarized project-specific examples of residuals management sampling and adaptive management approaches. McGee et al. (2011) and Cieniawski et al. (2009) provided case studies for cleanups that relied primarily on hydraulic dredging in riverine environments shallower than the EW. For the Fox River OU3 project, a tiered approach to sampling and triggering residuals management re-dredging and/or cover was used to achieve project objectives (McGee et al. 2011). For the Ashtabula River project, an extensive re-dredging strategy with specialized hydraulic dredging equipment was used (Cieniawski et al. 2009). For the Esquimalt Graving Dock Remediation project, an intensive sampling program and combined approach of selective mechanical redredging and placement of RMC were employed, showing placement of RMC to be more effective at reducing site-wide concentrations than additional redredge passes after completion of production dredging (Berlin et al. 2017).

3 RESIDUALS MANAGEMENT STRATEGIES

Successful dredging residuals strategies for contaminated sediment remediation projects commonly involve an adaptive approach that is based on monitoring data collected during and after dredging. The monitoring approach relies on detailed data relevant to potential residuals generation are gathered in dredge prisms during remedial design sampling. The residuals management decision framework for EW dredging will be established in remedial design and will include appropriate dredging performance standards and controls during dredging, post-dredging monitoring methods and decision criteria, and contingency residuals management measures such as RMC and re-dredging. Table 3-1 summarizes common residuals management tools used for environmental dredging, which includes BMPs used during dredging and post-dredging residuals management actions. The effectiveness, implementability, and cost of the residuals management tools are discussed to provide considerations for developing the residuals management framework during remedial design, and to provide context for the FS assumptions that are applied to the remedial alternatives.

Table 3-1

Summary of Tools for Management of Generated Residuals

Residuals Management Tool	Description	Effectiveness	Implementability	Cost
Standard BMPs specified in typical environmental dredging projects used during dredging, transport, and offloading	Dredging, transport, and offloading BMPs (e.g., equipment, operational controls, and monitoring) are typically defined in the Remedial Design phase. Standard BMPs include the following (see also FS Section 7.5.3): • Select appropriate dredge method and adjust methods in changing site conditions (e.g., dry excavation, environmental bucket, or digging bucket). • Select dredge methods to increase accuracy and minimize releases. Use equipment positioning methods that provide real-time positioning. Minimize slope failure; preclude underwater stockpiling or re-grading. • Perform tiered water quality monitoring during dredging and barge dewatering activities. Adjust dredging methods (e.g., cycle times) as necessary based on water quality measurements. • Control and filter release of barge effluent. • Use spill prevention measures during offloading and transloading.	• Standard BMPs are used to minimize sediment loss during environmental dredging activities, while some also help to ensure that removal extents are achieved. • Project-specific cleanup goals (e.g., RALs) may be achievable using standard BMPs, although additional residuals management tools are often required in some areas.	• Standard BMPs are a routine element of remedial dredging operations and are considered highly implementable. • Environmental closed buckets are implementable for softer sediment but are less effective at removing denser sediments.	Standard BMPs are the least costly, relative to the other residuals management tools.
Specialized BMPs specified in some environmental dredging projects	Specialized BMPs are sometimes specified during Remedial Design. Use of specialized BMPs may sometimes be effective at reducing suspended sediments (depending upon site conditions), but typically comes with trade-offs to production rates, costs, and design and construction complexity. Specialized equipment may include the following: • Silt curtain • Watertight barge and treatment of barge effluent	• Specialized BMPs have not been demonstrated to be better at limiting residuals than standard BMPs. • Project-specific cleanup goals (e.g., RALs) may be achievable using standard and specialized BMPs, although additional residuals management tools are often required in some areas. • Specialized equipment has not proven itself to be consistently more effective than standard BMPs at reducing loss of sediment during dredging activities under all site conditions; however, specialized equipment has the potential to reduce sediment loss when applied to appropriate site conditions.	• Site conditions (e.g., physical conditions of sediments, currents) dictate whether specific specialized equipment is implementable. • Full-length silt curtains are not considered implementable in high velocities, large tidal elevation changes, or deeper water depths (e.g., greater than 30 feet of water depth). • Watertight barges and water treatment are implementable but result in substantially more complex water management systems.	Additional specialized BMPs are moderately costly compared to other residuals management tools. Specialized BMPs could significantly increase base construction costs (e.g., collection and treatment of barge effluent).

Table 3-1
Summary of Tools for Management of Generated Residuals

Residuals Management Tool	Description	Effectiveness	Implementability	Cost
Monitored Natural Recovery	MNR is the process by which contaminant concentrations in sediment are reduced through a combination of physical, biological, and chemical processes so that surface sediment concentrations are reduced to acceptable levels within a specified timeframe. Natural recovery processes that could reduce generated residuals concentrations over time in the EW include sedimentation and mixing. MNR includes monitoring to measure progress toward performance goals, and adaptive management to determine if additional contingency remedial actions are necessary.	• MNR is similar to no action (following dredging), but includes monitoring and potential longer-term contingency actions to achieve performance goals. • MNR is likely to be more effective for concentrations marginally above performance goals in the EW, but is dependent on rates of sedimentation as well as mixing with deeper and cleaner undredged sediment.	• MNR is highly implementable following construction. • Potential contingency actions could lead to additional mobilizations for residuals management.	Low cost compared to other post-construction residuals management tools.
RMC over generated residuals	RMC is the placement of a thin layer of clean sand, similar to enhanced natural recovery cover, to cover and mix with the generated residuals in order to lower the surface concentrations post-construction. RMC layer thickness is typically 6 to 12 inches. The need for RMC is typically determined based on post-dredging sediment sampling.	• RMC placement is a common method for addressing elevated generated dredge residuals concentrations, and is considered highly effective based on demonstrated success at a wide range of sites. • RMC placement is typically used when standard BMPs are not sufficiently effective at minimizing the amount of generated residuals. • RMC placement provides a relatively high degree of predictability and confidence for post-construction concentrations because the thickness and chemical concentration of RMC materials is established prior to use. • RMC may be less effective for thick residuals or very high residuals concentrations.	• RMC is implementable and is commonly used to manage generated residuals in remedial dredging projects. • RMC placement adds construction time to environmental dredging above standard BMPs, but less than re-dredging. • The need for RMC placement would be determined based on post-dredge sampling.	RMC is a moderately costly post-construction residuals management tool, compared to re-dredging. Guidance documents identify RMC as very cost effective.
Re-dredging of generated residuals	Re-dredging is the attempted removal of the layer of generated residuals to lower the surface concentrations, should the surface concentration from generated residuals be over an unacceptable threshold concentration. 1 foot of sediment would likely be targeted for dredging and 2 feet of sediment would likely be removed when including allowable overdredge to account for construction tolerance.	• Re-dredging of thick layers of generated residuals may be effective (e.g., greater than 1 foot), but would have limited effectiveness for thin deposits due to the inability to capture the material in the dredge bucket. • The effectiveness of re-dredging generated residuals is highly uncertain due to the difficulty of capturing a thin layer of low-density generated residuals by mechanical dredging methods. Generated residuals are typically predominantly fine-grained sediment (silts and clays) that have been disturbed during dredging, and suspended into the water column, forming a very low-density nepheloid layer.	• Re-dredging is implementable and is sometimes used to manage generated residuals in remedial dredging projects, when the residuals layer is very thick or concentrations are very high. • Effective removal of a thin layer of generated residuals is challenging to implement due to the limits of dredge accuracy, difficulty in capturing low-density material, and the potential to displace and suspend residuals as a result of dredge bucket action. • Re-dredging could add multiple construction seasons due to the low production rate typical of performing thin dredge cuts.	Re-dredging is many times more expensive (approximately one order of magnitude) than the other residuals management tools.

Notes:
BMP – best management practice
EW – East Waterway
FS – Feasibility Study
MNR – monitored natural recovery
RAL – remedial action level
RMC – residuals management cover

3.1 Best Management Practices During Dredging

During environmental dredging, techniques, controls, and monitoring feedback are used to improve the accuracy of dredging (i.e., reduce the quantity of undisturbed residuals) and to minimize releases (i.e., generated residuals). Operational controls impose limitations on the operation of the equipment being used for removal activities. Standard BMPs are defined as those that are widely used in environmental dredging projects in the Puget Sound region. Specialized BMPs are defined as those that are used infrequently in the Puget Sound region and are less likely to be used on the EW project. All BMPs will be determined in remedial design.

3.1.1 Standard BMPs

For mechanical dredging, operational control BMPs that reduce re-suspension and loss of contaminated sediments may include the following (see also FS Section 7.5.3):

- **Select appropriate dredge equipment and adjust methods in changing site conditions**
  - Conduct intertidal sediment and shoreline bank soil excavation "in the dry" to the degree reasonably possible using land-based equipment.
  - Include an option for an environmental or sealed bucket, where practicable (proper sediment conditions exist).
  - Properly select the dredge bucket for site conditions (i.e., soft sediment versus debris and/or hard digging) to maximize sediment capture and optimize fill efficiency. Adjust methods in changing site conditions.
- **Select dredge methods to increase accuracy and minimize releases**
  - Perform dredging to the design dredge elevation in a single dredge event, as verified by periodic bathymetric surveys. Use sub-foot accuracy GPS for accurate bucket positioning.
  - Require a debris sweep prior to dredging in known debris areas (debris caught in dredging equipment can cause additional re-suspension and release of contaminated sediments).
  - Minimize the potential for slope failures by maintaining stable side slopes during dredging, including limiting the cut thickness of initial cut depths to avoid sloughing of the cut bank.

- Start dredging in upslope areas and move downslope to minimize sloughing.
- Slow the rate of dredge bucket descent and retrieval (increasing dredge cycle time).
- Limit operations during relatively high water velocity conditions (turbulence in the vicinity of the dredge bucket during high flow conditions can cause additional re-suspension and release of contaminated sediments).
- Prevent "sweeping" or leveling by pushing bottom sediments around with dredge equipment to achieve required elevations.
- Prevent interim stockpiling of dredge material under water.
- Prevent the overfilling of conventional clamshell (i.e., "open") buckets.
- Require the slow release of excess bucket water at the water surface.
- Contain drippage during the overwater swing of a filled bucket (e.g., by placing an empty barge or apron under the swing path during offloading or loading containers directly on barges).

- **Water quality monitoring**
  - Perform water quality monitoring during dredging to adaptively manage dredging operations and to comply with water quality requirements.
  - Adjust dredging methods (e.g., cycle times) as necessary based on water quality measurements.
- **Control dewatering operations**
  - Control and reduce the silt burden in runoff from barges using weirs, filtration, and settling.
  - Time water discharges to maximize settlement and filtration efficiency.
  - Prevent overfilling of barges to minimize spillage from barges.
- **Control transload operations**
  - Use barges that can be watertight during transit and transloading to collect and treat generated water.
  - Control and reduce the silt burden in runoff from rehandling areas, using filtration.
  - Use spill plates and spill prevention measures.

The effectiveness, implementability, and cost for standard BMPs, operational controls, and monitoring during dredging are presented in Table 3-1. Standard BMPs have been developed over the course of many environmental dredging projects, which, depending on site-specific factors, can be effective at reducing impacts to the environment during dredging and reducing the quantity of generated dredging residuals. Dredge residuals predictions for the EW and project experience shows that post-dredging performance goals (e.g., remedial action levels) are likely to be achieved in some locations and not achieved in other locations using only standard BMPs.

Standard BMPs are routinely implemented on environmental dredging projects in Puget Sound and are the least costly of the residuals management tools discussed in this appendix.

3.1.2 Specialized BMPs

Specialized BMPs have been developed for environmental dredging projects but have been used on a more limited basis. Specialized BMPs include silt curtains (a fabric enclosure to trap suspended sediment within the construction zone), and active treatment of barge effluent during dewatering operations.

Silt curtains and screens are specialized BMPs that have proven effective in reducing surface water turbidity in relatively quiescent environments and are a common BMP used to retain suspended sediment plumes at environmental dredging sites located in low-energy environments without deep water (Francingues and Palermo 2005). Water passes below or around fabric curtains because they are not typically sealed with the bottom. Water also discharges around the curtains when they are opened to allow the necessary passage of work equipment. As discussed in Bridges et al. (2010), based on a review of the available data, there is uncertainty as to whether silt curtains are effective in retaining contaminants within the curtain footprint, and there are also concerns that contaminants can migrate below the bottom of the curtain while the curtain is in place or upon curtain removal. Patmont and Palermo (2007) note that there are possible adverse impacts of enclosures on generated residuals because they contain suspended sediments and therefore concentrate residuals within the enclosure footprint.

Use of watertight barges to contain sediment and water and associated water treatment has been employed in recent environmental dredging projects on the Lower Duwamish Waterway during removal in Early Action Areas where high levels of contaminants were present in the sediment. The purpose of containing water on watertight barges is to help meet water quality standards for dissolved and suspended constituents. This approach can, to a limited degree, also reduce the load of suspended sediment in the construction area, thereby reducing the mass of suspended sediment redeposited as generated residuals; however, this would not likely reduce the sediment load substantially more than the standard BMP requirement of filtering barge runoff prior to discharge.

Table 3-1 summarizes the effectiveness, implementability, and cost for specialized BMPs. These BMPs have not been shown to significantly reduce the mass of generated residuals. Silt curtains could actually increase the thickness of generated residuals that settle in the dredging area by concentrating suspended solids. Water treatment can reduce the total mass of suspended sediment in the water column, but the contribution of dewatering activities to suspended solids load is typically small compared to the disturbance of the sediment by the dredge bucket. Therefore, use of watertight barges to contain sediment and water is unlikely to significantly reduce the mass of generated residuals.

In addition, these specialized BMPs are both difficult to implement and costly. Silt curtains would be a significant challenge to implement in the tidally influenced and deep waters of the EW, and use of water treatment would require the construction and maintenance of a complex and expensive treatment system.

3.2 Post-dredging Residuals Management Contingency Actions

BMPs employed during dredging will reduce the quantity of generated residuals, compared to standard maintenance dredging practices; however, the post-dredging performance goals are unlikely to be met in all locations. Therefore, a residuals management decision framework with contingency actions will be developed during remedial design. The decision framework will include a sampling plan and COC-specific triggers for contingency actions. A typical residuals management decision framework is tiered with appropriate contingency actions targeted for specific post-dredging conditions. The tiered framework could include no action, monitored natural recovery (MNR), RMC, and/or re-dredging for progressively higher post-dredging concentrations or thicker deposits of dredging residuals. As discussed below, re-dredging is only likely to be cost effective for very high concentrations or thick deposits of residuals.

The following sections describe the residuals management contingency actions that are commonly used on dredging projects for areas above contingency action criteria.

3.2.1 Monitored Natural Recovery

MNR is the process by which contaminant concentrations in sediment are reduced through a combination of physical, biological, and chemical processes so that surface sediment concentrations are reduced to acceptable levels within a specified timeframe. Natural recovery processes that could reduce generated residuals concentrations over time in the EW include sedimentation and mixing with recently deposited and deeper, undredged sediments. MNR includes monitoring to measure progress toward performance goals, and adaptive management to determine if additional contingency remedial actions are necessary. MNR as a remedial technology is described in FS Section 7.2.3.

The effectiveness, implementability, and cost for MNR placement are presented in Table 3-1. In the EW, the concentration in the biological active zone is likely to decrease over time due to natural recovery processes (e.g., mixing and sedimentation). In addition, MNR includes monitoring and potential contingency actions to meet performance goals. Contingency actions could include additional monitoring, placement of RMC, or re-dredging. MNR is likely to be more effective for concentrations marginally above performance goals in the EW, but is dependent on rates of sedimentation and mixing.

MNR is highly implementable. Monitoring can be incorporated into the long-term post-construction monitoring program (FS Appendix G). However, MNR could result in an additional mobilization should contingency actions become necessary.

MNR is the lowest-cost option of the post-dredging residuals management tools.

3.2.2 Residuals Management Cover

RMC refers to the placement of sand, similar to enhanced natural recovery (ENR), following dredging to reduce the effect of residuals on surface sediment concentrations. The short- and long-term mixing of the clean cover layer into underlying residuals can achieve remedial action levels and accelerate the natural recovery process in the biologically active zone. EW sediments are subject to regular mixing as a result of bioturbation and propeller wash (propwash) forces, and therefore the clean cover layer is anticipated to mix relatively quickly to enhance the recovery process and lower surface sediment concentrations, as illustrated in Figure 3-1. For dredging of the EW, which will take place over many construction seasons, RMC placement would likely occur at the end of all dredging, but depends on the decision framework developed in design.

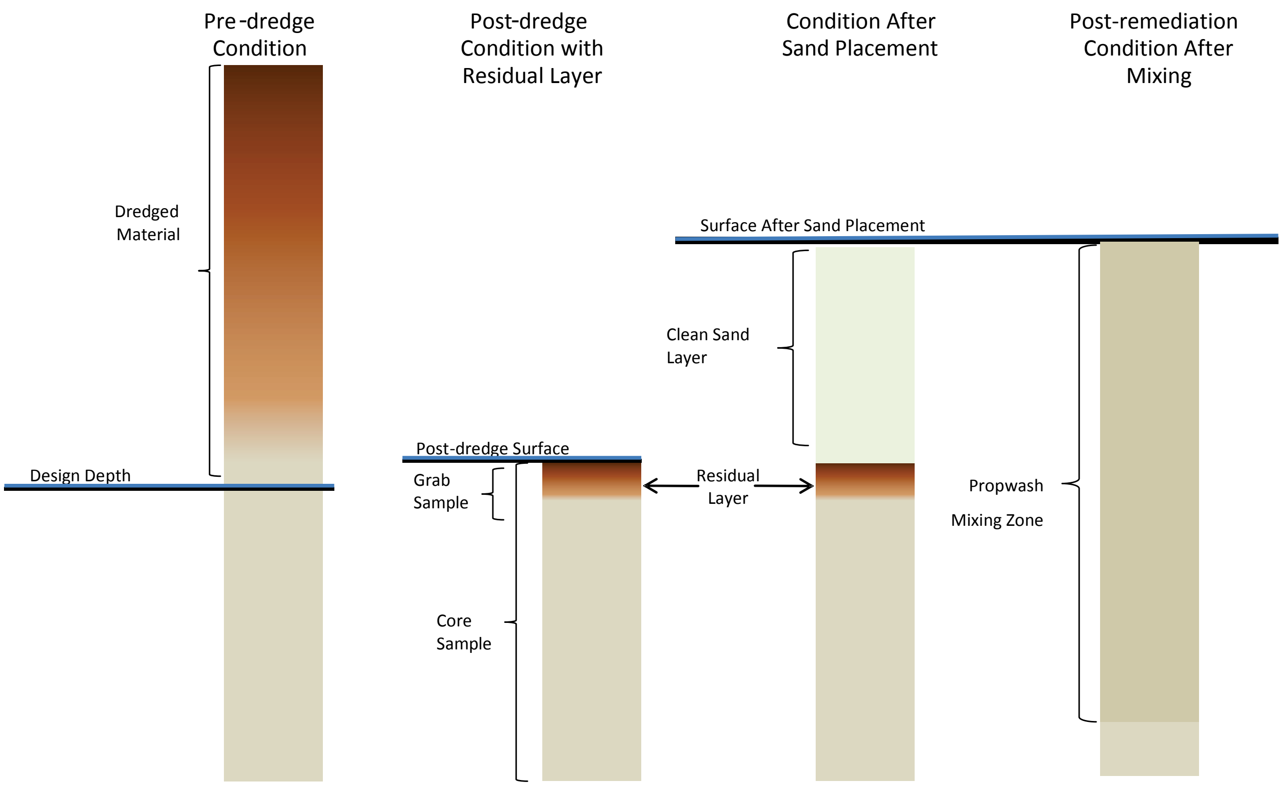

Figure 3-1

Conceptual Sediment Profiles to Illustrate Required Dredging, Placement of Residuals Management Sand Cover, and Post-remediation Mixing

The effectiveness, implementability, and cost for RMC placement are presented in Table 3-1. Case studies and guidance documents have highlighted that RMC has been effectively used for remediating thin layers of residuals. RMC has generally provided greater certainty in achieving project remedial objectives than natural recovery or re-dredging. RMC is less certain for remediating thick residuals layers or very high residuals concentrations where mixing would result in persistent elevated concentrations of contaminants.

Maintaining the native organic carbon content in the biologically active zone (BAZ) is important for reducing bioavailability of hydrophobic organic compounds that may persist at low levels after remediation (e.g., polychlorinated biphenyls [PCBs]). RMC is typically specified with low organic carbon content to minimize loss to the water column and minimize the generation of turbidity plumes during construction; however, total organic carbon (TOC) levels have rebounded to pre-construction levels in the EW and at nearby sites in 1 to 2 years following construction. Table 3-2 presents the average, maximum, and minimum TOC percentages for placement areas in the EW (following the 2005 Phase 1 Removal and RMC placement), and in the Lower Duwamish Waterway (Duwamish/Diagonal removal and capping/ENR areas and Slip 4 removal and backfill). All year 0 post-construction data collected show low TOC concentrations immediately after construction. In year 1 post-placement, three of four datasets have TOC concentrations in the range of pre-construction concentrations. By year 2 post-placement, all four areas increased to within the range of pre-construction concentrations. The mechanisms for TOC rebound are thought to be: a) biological activity during benthic recolonization;
b) sedimentation of sediment with higher TOC concentrations; and c) mixing with native sediments (in the case of RMC and ENR).

Table 3-2
Total Organic Carbon Over Time in Sand Placement Areas for the EW and Nearby Areas

Parameter	Summary of %TOC Results						
	Pre-construction	Year 0 Post-placement	Year 1 Post-placement	Year 2 Post-placement	Year 3 Post-placement	Year 4 Post-placement	Year 5 Post-placement
East Waterway - Phase 1 Removal and RMC Area[a]							
Average	1.4		1.1	1.1	1.5		
Maximum	2.3		2.3	1.9	2.8		
Minimum	0.6		0.4	0.5	0.1		
n	29		15	17	11		
Duwamish Diagonal Capping and ENR Areas[b]							
Capping Area							
Average	2.6	0.3	1.9	1.6	1.7	1.7	1.7
Maximum	9.0	0.6	5.7	3.0	2.9	3.6	2.8
Minimum	0.2	0.0	0.1	0.1	0.3	0.1	0.2
n	43	7	7	8	8	8	8
ENR Area							
Average	1.5	0.1	0.3	1.1	0.9	1.3	
Maximum	1.8	0.3	0.6	1.5	1.3	1.7	
Minimum	1.1	0.0	0.1	0.7	0.3	0.6	
n	7	7	7	7	7	7	
Slip 4 Early Action Area[c]							
Average	2.9	0.2	2.9	3.2	2.6		
Maximum	11.5	0.4	3.8	6.3	6.9		
Minimum	0.8	0.1	1.5	0.8	0.2		
n	41	12	13	33	26		

Notes:

a. All data from East Waterway Phase 1 Removal Action Recontamination Monitoring Data Reports (Windward 2007, 2008a, 2008b).

b. All data from Lower Duwamish Waterway Feasibility Study (LDW FS) Dataset (AECOM 2012). Pre-construction data for the Duwamish Diagonal capping area were based on the LDW FS baseline dataset and were collected to support cleanup of the Early Action Area. All other data were collected from sampling stations established for the purpose of long-term cap and ENR monitoring.

c. Pre-construction data were based on the LDW FS baseline dataset (AECOM 2012) and were collected to support cleanup of the Slip 4 Early Action Area. All other data were collected for the purpose of long-term monitoring (Integral 2015).

Blank cell – data not collected
ENR – enhanced natural recovery
EW – East Waterway
n – count
RMC – residuals management cover
TOC – total organic carbon

RMC is highly implementable and is commonly employed in the Puget Sound region for environmental dredging projects and for meeting anti-degradation standards for maintenance dredging projects. RMC placement adds construction time to remediation projects, but less than re-dredging.

RMC is moderately costly compared to the other residuals management tools, and guidance documents identify RMC as very cost-effective for managing dredging residuals.

3.2.3 Re-dredging

Re-dredging is another commonly employed residuals management contingency measure, typically reserved for undisturbed residuals, areas of very high generated residuals concentrations, or areas with thick generated residuals deposits. Additional dredging of discrete areas can be conducted to remove contaminant mass left behind after the first round of dredging operations are complete. Re-dredging is also referred to as a "cleanup pass" and is usually conducted in such a way as to attempt to remove only a thin surficial layer of material, with the intent of removing the residuals layer and a minimal thickness of underlying clean material. Due to typical dredge equipment tolerances, 1 foot of sediment would typically be targeted for dredging and 2 feet of sediment would typically be removed when including an allowance for overdredging.

Re-dredging has had mixed success on remediation projects. Patmont and Palermo (2007) report that performing multiple passes and cleanup passes to control residuals have often been inefficient and ineffective. Contingent cleanup passes are typically reserved for remediation areas above contingency re-dredge criteria, where COC concentrations are usually several times above action levels and are not complicated by underlying bedrock, hardpan surfaces, or very soft sediments.

Re-dredging is implementable; however, accurately targeting a thin layer of low-density sediment in deep water is challenging and may require reduced dredging cycle times, slower production rates, and unnecessary removal of a relatively large volume of clean overdredge material. Re-dredging can add multiple dredging seasons to a large remediation project.

Re-dredging is the most costly of the residuals management measures, and many times more costly than RMC placement.

4 CONCEPTUAL QUANTITATIVE ANALYSIS

A conceptual quantitative analysis was performed to compare residuals management contingency actions to inform FS modeling, construction timeframe, and cost estimates. The quantitative analysis may also inform the residuals management decision framework developed during remedial design. As discussed above, dredge areas within the EW will likely include multiple residuals management approaches, depending on location-specific conditions following dredging. Therefore, this analysis is intended to compare the relative benefits and costs of different residuals management actions, but the analysis is not appropriate for use in selecting a single residuals management approach to be used across the EW.

4.1 Estimate of Post-construction Concentrations for Residuals Management Contingency Actions

Table 4-1 presents a series of calculations for estimating the relative range of post-construction concentrations for residuals management contingency actions in dredged areas, including: 1) standard BMPs during dredging (no active residuals management contingency actions after dredging); 2) contingency RMC (9-inch average thickness) after dredging; 3) contingency RMC (18-inch average thickness) after dredging; 4) contingency re-dredging; and 5) contingency re-dredging followed by RMC (9-inch average). Consistent with sensitivity analyses presented in FS Appendix J, only total PCBs were analyzed because it contributes the most to site risks and is distributed throughout much of the waterway. The predicted concentrations were estimated using a consistent set of assumptions; however, many factors affect the actual concentrations measured as part of confirmatory sampling, including actual number of dredge cuts, dredge equipment, timing of contingency dredging and cover placement, timing of confirmatory sampling, vessel activity and associated propwash during dredging and RMC placement, bulk density of residuals layer, and other factors.

Table 4-1

Comparison of Estimated Total PCB Sediment Concentrations Associated with Residual Management Tools

Item No.	Item	Unit	Low Loss	Medium Loss	High Loss
1	***Standard BMPs During Dredging (No Active Residuals Management Contingency Measures Following Dredging [i.e., MNR])***				
1.01	Thickness of Residuals	cm	3.1	5.1	7.2
1.02	Concentration of Residuals	µg/kg	470	640	980
1.03	Concentration of Underlying Sediment	µg/kg	15	15	15
1.04	**Concentration of the BAZ**	**µg/kg**	**160**	**330**	**710**
1.05	**Concentration in the Upper 2 Feet**	**µg/kg**	**38**	**67**	**129**
2	***Contingency Residuals Management Cover (9 Inches Average)***				
2.01	Percent of Resuspended Residuals during Sand Placement	%	10%	10%	10%
2.02	Thickness of Resuspended Residuals during Sand Placement	cm	0.31	0.51	0.72
2.03	Concentration of Residuals	µg/kg	470	640	980
2.04	Thickness of RMC	in	9	9	9
2.05	Concentration of Underlying RMC	µg/kg	2	2	2
2.06	Concentration of Underlying Sediment	µg/kg	15	15	15
2.07	**Concentration of the BAZ**	**µg/kg**	**17**	**35**	**72**
2.08	**Concentration in the Upper 2 Feet**	**µg/kg**	**12**	**15**	**22**
3	***Contingency Residuals Management Cover (18 Inches Average)***				
3.01	Percent of Resuspended Residuals during Sand Placement	%	10%	10%	10%
3.02	Thickness of Resuspended Residuals during Sand Placement	cm	0.31	0.51	0.72
3.03	Concentration of Residuals	µg/kg	470	640	980
3.04	Thickness of RMC	in	18	18	18
3.05	Concentration of Underlying RMC	µg/kg	2	2	2
3.06	Concentration of Underlying Sediment	µg/kg	15	15	15
3.07	**Concentration of the BAZ**	**µg/kg**	**17**	**35**	**72**
3.08	**Concentration in the Upper 2 Feet**	**µg/kg**	**7.6**	**10**	**17**
4	***Contingency Re-dredging***				
4.01	Thickness of Re-dredging	ft	2.0	2.0	2.0
4.02	Contribution from Underlying Sediment				
4.03	Thickness of Underlying Sediment Dredged	cm	57.9	55.9	53.8
4.04	Percent Loss of Underlying in situ Material Dredged	%	3%	5%	7%
4.05	Residuals Contribution from Underlying Sediment	cm	1.7	2.8	3.8
4.06	Concentration of Underlying Sediment	µg/kg	15	15	15
4.07	Contribution from Re-dredged Residuals				
4.08	Thickness of Re-dredged Residuals	cm	3.1	5.1	7.2
4.09	Percent Loss of Re-dredged Residuals	%	20%	50%	80%
4.10	Residuals Contribution from Re-dredged Residuals	cm	0.6	2.6	5.8
4.11	Concentration of Re-dredged Residuals	µg/kg	470	640	980
4.12	Weighted Average Values				
4.13	Thickness of Residuals	cm	2.4	5.3	9.5
4.14	Concentration of Residuals	µg/kg	135	313	599
4.15	Concentration of Underlying Sediment	µg/kg	15	15	15
4.16	**Concentration of the BAZ**	**µg/kg**	**43**	**170**	**570**
4.17	**Concentration in the Upper 2 Feet**	**µg/kg**	**20**	**41**	**110**
5	***Contingency Re-dredging followed by Residuals Management Cover (9 Inches Average)***				
5.01	Percent of Resuspended Residuals during Sand Placement	%	10%	10%	10%
5.02	Thickness of Resuspended Residuals during Sand Placement	cm	0.24	0.53	0.95
5.03	Concentration of Residuals	µg/kg	135	313	599
5.04	Thickness of RMC	in	9	9	9
5.05	Concentration of Underlying RMC	µg/kg	2	2	2
5.06	Concentration of Underlying Sediment	µg/kg	15	15	15
5.07	**Concentration of the BAZ**	**µg/kg**	**5**	**19**	**59**
5.08	**Concentration in the Upper 2 Feet**	**µg/kg**	**11**	**13**	**19**

Notes:
Calculated values are rounded to two significant digits.
µg/kg – micrograms per kilogram
BAZ – biologically active zone
BMP – best management practice
cm – centimeter
ft – foot
in – inch
MNR – monitored natural recovery
PCB – polychlorinated biphenyl
RMC – residuals management cover

As discussed above, the concentration and thickness of generated residuals under any residuals management contingency approach will vary across the site, based on the location-specific concentration profile, dredging depth, and conditions (e.g., debris, riprap, and structural setbacks). For this analysis, the range of box model inputs for low, medium, and high estimates of residuals thickness and concentration (FS Appendix J) was used to estimate the range of residuals that could remain in various locations across the site. The concentrations presented in Table 4-1 are not representative of predicted site-wide concentrations, but rather represent the post-construction conditions that could be encountered in any given location of the EW during confirmatory sampling, depending on location-specific conditions.

The first section of Table 4-1 presents the estimated range of total PCB concentrations that could be observed following dredging using standard BMPs during dredging, followed by MNR without contingency residuals management actions. Following completion of required dredging, the total PCB concentrations in the biological active zone could range from 160 to 710 micrograms per kilogram (μg/kg) dry weight (dw). Because of the impact of vessel scour on the site, the location-specific concentrations were also calculated, assuming 2 feet of propwash mixing, resulting in a range of total PCB concentrations from 38 to 130 μg/kg dw. Location-specific total PCB concentrations therefore may range from 38 to 710 μg/kg dw, depending on the concentration and thickness of generated residuals and the degree of propwash.

Section 2 of Table 4-1 estimates the location-specific concentrations following the placement of RMC using the replacement values calculation methodology developed in this FS, which estimates a percentage of the residuals layer resuspended during RMC placement and deposited on the surface of the RMC (9-inch average RMC layer thickness; see FS Appendix B, Part 3A). Consistent with the literature discussions cited above, RMC is predicted to significantly reduce post-construction concentrations and the range of uncertainty in those concentrations. The range of post-placement total PCB concentrations is estimated from 17 to 72 μg/kg dw in the BAZ and 12 to 22 μg/kg dw following 2 feet of mixing, for a total range of 12 to 72 μg/kg dw, depending on the starting thickness and concentration of the residuals layer and the depth of mixing following placement. It is important to note that the lower predicted concentrations of the ranges stated above are below that which are predicted to be achieved on a site-wide basis due to removal limitations associated with structural setbacks and the presence of riprap keyways and underpier slopes (see FS Appendix A, Section 4.1.1). The site-wide lowest achievable total PCBs spatially-weighted average concentration (SWAC) was estimated to be 57 μg/kg dw, with an effective bioavailable concentration of 34 μg/kg dw (FS Appendix A).

RMC is likely to meet the post-construction performance goals and will result in concentrations in most RMC placement locations that are below the site-wide lowest possible achievable SWAC. Low concentrations are predicted following RMC placement because, while the generated residuals layer has relatively high concentrations of total PCBs (compared to post-remediation goals), the predicted generated residuals layer is thin and does not represent a large mass of contamination. It is also important to note that the biological active zone is expected to rebound to baseline levels of organic carbon within a few years following RMC placement, due to organic carbon in incoming sediment, and the load of organic material that accumulates from biological activity at the site.

Section 3 of Table 4-1 estimates the concentration following placement of a thicker layer of RMC. The range of post-placement total PCB concentrations is estimated from 17 to 72 μg/kg dw in the BAZ, 7.6 to 17 μg/kg dw following 2 feet of mixing, for a total range of 7.6 to 72 μg/kg dw, depending on the starting thickness and concentration of the residuals layer and the depth of mixing following placement. The predicted concentration range is very similar to the thinner layer of RMC because the thicker RMC layer is similar in concentration to the concentration of sediment located below the required dredge elevation (e.g., native sediment) that underlies the residuals layer and therefore does not substantially reduce the mixed concentration.

Section 4 of Table 4-1 estimates the concentration following re-dredging of the generated residuals layer. The range of post-placement total PCB concentrations is estimated from 43 to 570 μg/kg dw in the BAZ, 20 to 110 μg/kg dw following 2 feet of mixing, for a total range of 20 to 570 μg/kg dw, depending on the starting thickness and concentration of the residuals layer and the depth of mixing following placement. Consistent with the literature discussions cited above, effectiveness of re-dredging is predicted to have a higher degree of uncertainty because the low-density residuals layer is more likely to be not captured by or re-released from the dredge bucket. The percent loss of the low-density residuals layer during the contingency re-dredge pass was estimated to range from 20 to 80% for this reason (line item 4.09). Note that the timing of re-dredging will affect the degree to which the residuals layer will have consolidated or mixed with deeper, undredged sediment prior to re-dredging.

Section 5 of Table 4-1 assumes that re-dredging is followed by RMC placement for management of residuals. The range of post-placement total PCB concentrations is estimated from 5 to 59 µg/kg dw in the BAZ, 7.9 to 37 µg/kg dw following 2 feet of mixing, for a total range of 7.9 to 59 µg/kg dw, depending on the starting thickness and concentration of the residuals layer and the depth of mixing following placement. The same uncertainties discussed above for RMC and re-dredging will both apply. Note that, as discussed above, these concentrations are below the site-wide lowest possible achievable SWAC when considering constructability (FS Appendix A); concentrations this low may or may not be observed in a given area of the EW as part of confirmatory sampling. This approach has the largest construction timeframe and cost implications, as discussed in the following section.

4.2 Estimate of Construction Timeframe and Cost for Residuals Management Contingency Actions

The construction timeframes and costs were estimated for the residuals management contingency actions normalized to 100 acres of remediation. For RMC, all unit costs and durations were consistent with the FS Alternatives (FS Appendix E). For re-dredging, the construction duration was assumed to be half the FS estimate of 1,100 cy/day because of the additional time required for thin-lift precision dredging. Re-dredging was assumed to target 1 foot of removal and result in 2 feet of removal due to overdredging. The unit cost for disposal of dredged sediment was not changed from FS Appendix E. The resulting construction timeframes and costs for the residuals management contingency actions are presented in Table 4-2.

The costs and construction times associated with the use of standard BMPs (line item 1) are not quantified for this analysis because the use of these measures is already incorporated into the base dredging costs and construction timeframes for the alternatives.

The unit construction timeframe and cost to complete 100 acres of RMC placement (line item 2) is 1.3 construction seasons and $7.8 million dollars. Doubling the RMC placement thickness approximately doubles the construction time and costs (line item 3). One hundred acres of contingency re-dredging (line item 4) is estimated to take 5.9 years and cost $72 million dollars, which is considered disproportionately costly compared to the anticipated reduction in concentrations associated with that contingency action. Combining re-dredging and RMC (line item 5) results in 7.2 years of construction and $79 million dollars for 100 acres of action. Although this combination results in the lowest anticipated concentrations of the contingency measures presented here, costs are considered disproportionate to the reduction in concentrations, especially considering the conditions of the EW that also influence the final concentrations of sediments in the waterway as a whole, such as propwash mixing, incoming sediment concentrations, underpier remediation, and structural setbacks.

Table 4-2
Residuals Management Contingency Measures Construction Timeframes and Costs Normalized to 100 Acres

Description	Construction Timeframe (years per 100 acres)	Cost ($ millions per 100 acres)
1. Standard BMPs during Dredging (No Active Residuals Management Contingency Measures Following Dredging)	0[a]	$0[a]
2. Contingency Residuals Management Cover (9 Inches Average)	1.3	$7.8
3. Contingency Residuals Management Cover (18 Inches Average)	2.6	$16
4. Contingency Re-dredging	5.9	$72
5. Contingency Re-dredging followed by Residuals Management Cover (9 Inches Average)	7.2	$79

Notes:
a. Standard environmental BMPs increase the construction duration and costs for dredging above maintenance dredging, but the additional time and costs are not quantified here. The FS base cost and construction timeframe estimates (FS Appendix E) assume that standard BMPs would be used.

BMP – best management practice
FS – Feasibility Study

5 SUMMARY AND CONCLUSIONS

This appendix provides a review of literature and studies of dredging residuals, presents qualitative information on dredging residuals estimates, and quantitative comparison of residuals management contingency measures. In summary, this information supports the placement of a thin sand layer, RMC, as the most cost-effective way to reliably reduce surface sediment concentrations following dredging. Therefore, the FS alternatives assume that RMC will be placed over the entire dredge footprint as well as undredged areas adjacent to dredged areas (the "interior unremediated islands"; see Section 2.3). These assumptions are used to develop the box model predictions, construction times, and costs for comparing the alternatives on a common basis.

Actual residuals management actions will be based on the residuals management framework, to be developed during design and confirmatory sampling results following dredging. It is expected that more than one residuals management contingency action will be employed; however, the SWACs, costs, and construction timeframes for the remedial alternatives are based on the application of RMC in all dredging areas. Additional evaluation of potential residuals management contingency actions will be addressed following additional data collection that will be conducted during design.

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APPENDIX C – REMEDIATION AREA EVALUATION

EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

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1 INTRODUCTION

Section 6 of the Feasibility Study (FS) describes the selected remedial action levels (RALs) for the East Waterway (EW) and use of Thiessen polygons to establish the remediation area. This appendix describes the sensitivity of the remediation area using inverse distance weighted (IDW) interpolation methods as an alternate method for interpolation of total polychlorinated biphenyl (PCB) sediment concentrations. This appendix also presents a list of samples with non-detect reporting limits above the RALs.

2 COMPARISON OF PCB INTERPOLATION METHODS

This section compares two different methods of interpolation—Thiessen polygon and IDW—for developing the remediation footprint for total PCBs.

2.1 PCB Remedial Action Level

One RAL established for PCBs is 12 milligrams per kilogram (mg/kg) organic carbon (OC)-normalized, which is equal to the Sediment Quality Standard (SQS) and the benthic Sediment Cleanup Objective (SCO) under the Washington State Sediment Management Standards (SMS). Selection of an OC-normalized RAL is more appropriate than use of a dry weight (dw) RAL because the organic content affects the bioavailability, and thus the toxicity, which can then reduce the risk of adverse effects to the benthic community from PCBs. This RAL is consistent with the RAL selected for PCBs in the U.S. Environmental Protection Agency (EPA's) Lower Duwamish Waterway (LDW) Record of Decision (EPA 2014). Other PCB RALs evaluated in the FS are 7.5 mg/kg OC and 5.0 mg/kg OC (see FS Section 6).

The OC-normalized concentration of each sample varies based on the PCB dw concentration (in micrograms per kilogram [μg/kg] dw) and on the percent OC content (Equation 1). Higher or lower OC content for a specific PCB dw concentration affects whether individual samples are above or below the RAL. For example, once OC-normalized, a PCB concentration of 200 μg/kg dw can be above or below the OC-normalized RAL of 12 mg/kg OC depending on the OC content of the sample. PCB OC-normalized concentrations (mg/kg OC) were calculated using sample-specific OC content and PCB dw concentration (μg/kg dw). Each PCB OC-normalized result was compared to the RAL to determine the remediation area for PCB RAL exceedances in the FS.

$$C_{oc} = C_{dw} * f_{oc} / UCF \tag{1}$$

where:

C_{oc}	=	OC-normalized concentrations (mg/kg OC)
C_{dw}	=	dw concentration (μg/kg dw)
f_{oc}	=	fraction of OC
UCF	=	unit conversion factor (1,000 μg/mg)

2.2 Interpolation Methods

The FS uses Thiessen polygons to establish the remediation area. As described in Section 6.1.2.1 of the FS, interpolation using Thiessen polygons was determined to be an appropriate interpolation method to evaluate the extent of contaminant of concern (COC) concentrations throughout the entire Operable Unit (OU) due to the high density of data points with good spatial distribution. Thiessen polygons for risk driver COCs were then compared to the COC-specific RAL and used to determine the areal extent of remediation. A Thiessen polygon refers to the boundary of the area that surrounds a unique data point. Thiessen polygons are a commonly used method for characterizing the distribution of sediment chemical contamination and biological effects by assigning chemical concentrations or other values to areas where no actual data exist (i.e., un-sampled areas). Thiessen polygons have boundaries that define the area that is closest to each point relative to all other points. The polygon size and shape is determined by the proximity of neighboring sample locations. The concentration within the entire polygon is assumed to be equal to the concentration of the sample point located at the centroid. Thus, every un-sampled area is assigned the value of its nearest measurement point. For the FS, Thiessen polygons have been used to identify areas that are above or below RALs.

IDW is an interpolation method that assigns values to unknown points using a weighted average of the values from nearby known sample points. It assigns weights based on the inverse of the distance to each known point. IDW is better suited to interpolate dw sediment concentrations rather than OC-normalized concentrations. In order to develop an IDW interpolation of OC-normalized concentrations, IDW would have to be conducted independently for both PCB dw concentrations and total organic carbon (TOC) concentrations, and then those grid layers would have to be combined to generate an IDW for OC-normalized concentrations. This approach compounds the uncertainties in the IDW interpolation because two different parameters would be interpolated and then combined. Therefore, the level of uncertainty with IDW for OC-normalized concentrations is likely greater than uncertainties associated with OC-normalized interpolation based on Thiessen polygons.

2.3 Sensitivity of Remediation Area for PCBs

This section presents the extent of the area for total PCBs above the RAL of 12 mg/kg OC using Thiessen polygons and above the dw equivalent of the RAL using IDW. As noted above, because of uncertainties in generating an OC-normalized IDW interpolation, only dw total PCB concentrations are interpolated with the IDW method. Attachment 1 to this appendix describes the methods to optimize the parameters used for the IDW interpolation that is discussed in this section.[1] In order to compare the remediation area using IDW (using dw concentrations) to the remediation area using Thiessen polygons (using OC-normalized concentrations), the OC-normalized RAL was converted to a dw equivalent using the average OC content for the site (1.6%), which is equal to 192 µg/kg dw. However, applying this approximate equivalent OC content to the waterway as a whole is technically not an accurate measure of exceedances of the proposed RAL. In practice, the measured OC content of each sample should be used to estimate the dw equivalent for that sample.

The remediation area using Thiessen polygons and the RALs in Section 6 of the FS is presented in Figure 1. The black hatched area contains sediments above the PCBs RAL of 12 mg/kg OC, and is thus included in the remediation area. The green portion constitutes the remainder that is included in the remediation area because of sediment concentrations above any of the other RALs besides PCBs. Figure 2 presents the area above 192 µg/kg dw using IDW, shown in orange hatching. The area above any of the other COC RALs besides PCBs is also shown in green, as in Figure 1.

The exact size and shape of the hatched areas on Figures 1 and 2 vary slightly, as shown in Figure 3. Some PCB areas using Thiessen polygons (black hatch) result in a larger area than when using IDW (orange hatch), but other areas result in a larger area when using IDW than Thiessen polygons. These differences are largely because the dw equivalent is based on site-

[1] The IDW parameterization used in this appendix differs from the IDW parameterization used in the EW SRI (Windward and Anchor QEA 2014). The maps in the main portion of the SRI presented the same parameterization used in the LDW, whereas in the present EW FS, the parameterization was optimized for the EW. Attachment 1 shows the optimized parameterization for the EW when using both surface and shallow subsurface sediment (0 to 2 feet), which included the maximum result for sediment core samples in the upper 2 feet below mudline north of the Spokane Street Bridge, are combined. For comparison purposes, the SRI also presents the optimized parameterization for the EW using only surface sediment data in Appendix D of the SRI, which resulted in very similar IDW outcomes to those based on the LDW parameterization.

wide average 1.6% OC rather than the actual OC value measured in each sample. The dw equivalent is not accurate in areas where the OC differs from 1.6% (the average for the site). If actual TOC from a sampling area were to be used that differs from 1.6%, the dw equivalent value would not be 192 µg/kg dw. Other differences are the result the interpolation method, which produces slightly different edges or boundaries.

Nearly all of the area where the PCB interpolation method differs between the two methods is already above one of the other COC RALs (i.e., most hatching is within the yellow area on Figure 3), triggering remediation regardless of PCB concentration. As shown on Figure 3, the discrepancies in the PCB interpolation method are minor compared to the overall remediation footprint.

Table 1 summarizes the footprint associated with each interpolation method for total PCBs. The total area using Thiessen polygons above the OC-normalized RAL of 12 mg/kg OC (108 acres) is greater than the area using IDW above the dw equivalent of 192 µg/kg dw (105 acres). When the areas above the PCB trigger (based on either interpolation method) are combined with the areas exceeding RALs other than PCBs, a larger remedial footprint results when using Thiessen polygons (labeled as Combined Areas in Table 1). Thus, the Thiessen polygon method with the OC-normalized RAL is a more conservative method (i.e., larger remedial footprint) than the IDW method for establishing the EW remediation area (see Table 1).

Table 1
Summary of Area for Thiessen Polygons and IDW for Total PCBs

Interpolation Method	PCB Hatched Area		Portion Outside PCB Hatched Area Above RALs for Other COCs (Non-hatched Green Area in Figures 1 and 2)		Combined Areas (Hatched and Yellow Area in Figure 3)	
	Acres	Percent of Study Area	Acres	Percent of Study Area	Acres	Percent of Study Area
Thiessen Polygons (total PCBs above 12 mg/kg OC[1])	108	69%	15	9%	122	77%
IDW (total PCBs above 192 µg/kg dw[2])	105	66%	14	9%	118	75%

Notes:
1. 12 mg/kg OC is the RAL for total PCBs evaluated for this analysis.
2. 192 µg/kg dw is based on conversion of the total PCB RAL (12 mg/kg OC) to dry weight using the average percentage of organic carbon in surface sediments in the East Waterway (1.6 %).

The Study Area is equal to 157 acres.
Green areas (Figures 1 and 2) based on all areas that exceed RALs for all other chemicals except for PCBs.
Yellow area (Figure 3) based on Thiessen polygons for all areas with RAL exceedances, including PCBs.
All estimates of acreage and percent of Study Area are rounded to nearest whole number.

µg – microgram
COC – contaminant of concern
dw – dry weight
IDW – inverse distance weighted
kg – kilogram
mg – milligram
NA – not applicable
OC – organic carbon
PCB – polychlorinated biphenyl
RAL – remedial action level

3 EFFECT OF SAMPLE DENSITY AND DETECTION LIMITS ON REMEDIATION AREAS

This section evaluates the effect of existing sample density and detection limits on the remediation areas developed for the EW in the FS alternatives.

3.1 Sample Density

Approximately 340 surface sediment and shallow subsurface sediment samples were used to develop the remediation footprint for the 157-acre EW (e.g., see FS Figure 6-1). Most locations were analyzed for the SMS suite of contaminants, which includes all benthic SMS risk drivers (including PCBs) and carcinogenic polycyclic aromatic hydrocarbons (cPAHs). Two COCs were sampled at less spatial coverage compared to the other risk drivers: tributyltin (TBT) and dioxins/furans. As shown in FS Figure 6-1, TBT RAL exceedances were co-located with exceedances of other COCs in all locations except one; in that location, the existing Theissen polygon was added to the remediation footprint. As shown in FS Figure 6-4, dioxin/furan RAL exceedances were co-located with exceedances of other COCs in all locations except three; the polygons associated with these locations were added to the remediation footprint. Since these contaminants are mostly co-located with the other risk drivers, and because the remediation area covers most of the EW, additional TBT and dioxin/furan samples are not expected to appreciably alter the remediation footprint used for the FS alternatives. The delineation of the actual remediation footprint will be refined with additional sampling during remedial design.

3.2 Reporting Limits Above the SQS at Stations Outside the Remediation Area

Three locations have non-detected results with reporting limits that are greater than the SQS for at least one COC[2] and are outside of the total remedial footprint (based on the RAL set including 12 mg/kg OC for PCBs). As shown in Table 2, two locations had reporting limit (RL) exceedances for 2,4-dimethylphenol, and the RLs for butyl benzyl phthalate and 1,4-dichlorobenzene each exceeded the SQS at one location. All three of these chemicals were rarely detected at concentrations above the SQS in the EW, with only one detected exceedance for 2,4-dimethylphenol and nine detected exceedances for butyl benzyl

[2] The benthic COCs identified in the EPA-approved ERA (Windward 2012) did not include chemicals that were never detected above the SQS (e.g., 1,2,4-trichlorobenzene and hexachlorobenzene).

phthalate and 1,4-dichlorobenzene, which represents less than 5% of the total surface sediment samples.

While there is some uncertainty associated with RL exceedances, the risk to benthic organisms is not considered significant because: 1) matrix interferences (that result in higher RLs in the laboratory) only occur in a few samples; 2) the SQS only identifies areas with the potential to have adverse effects to benthic organisms; 3) the only chemical with reporting limits above the cleanup screening level (CSL) is 2,4-dimethylphenol, which is a case where the SQS and CSL are the same value; and 4) all detected COCs are below RALs in these locations.

The EW will be sampled during remedial design to refine the remediation footprint.

Table 2
Stations Outside the Remediation Area with Reporting Limits above SQS

Location Name	Depth	Chemical	Dry Weight Reporting Limit (µg/kg dw)	Carbon Normalized Reporting Limit (mg/kg OC)	SQS	CSL	CSL/SQS Unit	Above SQS	Above CSL
EW-108	0-10 cm	2,4-Dimethylphenol	53 U	NC	29	29	µg/kg dw	Yes	Yes
EW-108	0-10 cm	Butyl benzyl phthalate	53 U	9.5 U	4.9	64	mg/kg OC	Yes	No
EW-RM-18	0-10 cm	1,4-Dichlorobenzene	20 U	3.5 U	3.1	9	mg/kg OC	Yes	No
S-64/40	0-10 cm	2,4-Dimethylphenol	49 U	NC	29	29	µg/kg dw	Yes	Yes

Notes:
1. OC normalization was not performed for samples outside of the carbon normalization range from 0.5% to 4% TOC.

µg – microgram
cm – centimeter
dw – dry weight
CSL – cleanup screening level
kg – kilogram
mg – milligram
NC – not calculated
OC – organic carbon
SQS – sediment quality standards
TOC – total organic carbon
U – result not detected at the reporting limit shown

4 SUMMARY

The methods used to develop the remediation footprints are reasonable for the FS development and comparison of alternatives. The FS establishes the remediation area using Thiessen polygons based on an OC-normalized RAL, which is preferred to an IDW interpolation using dw concentrations for the following reasons:

- The organic content in sediment affects the bioavailability, and thus toxicity, of PCBs. Use of a dw threshold of 192 µg/kg dw does not consider the influence of area- or sample-specific organic content and its effect on toxicity and bioavailability.
- The use of a dw PCB concentration for mapping the remedial footprint is not consistent with the associated RAL for PCBs of 12 mg/kg OC. Using the PCB dw equivalent based on average site-wide TOC content would not accurately map the OC-normalized RAL because sample-specific TOC content is accurate for each sample.
- Although remediation areas in the LDW were interpolated using a dw equivalent of the OC-normalized RAL (12 mg/kg OC) as a surrogate for the OC-normalized RAL, this was done in part because the LDW has lower data density in areas that was less evenly distributed than what is available for the EW. However, the remedial design footprint for the LDW is currently based on a RAL of 12 mg/kg OC.
- The remedial footprint that is established for FS purposes is intended to provide a reasonable basis for determining the area and volume associated with each remedial alternative. Therefore, it is important to apply a consistent set of rules (and assumptions) to develop the remedial footprint for FS purposes to avoid biasing a remedial alternative. The FS compares each remedial alternative relative to other alternatives, but does not attempt to finalize the remedial footprint, which is completed during remedial design.

This appendix explored the uncertainty associated with interpolation of areas using either Thiessen polygons or IDW, the sampling density of COCs, and detection limits above RALs. In all cases, these uncertainties are relatively minor primarily because the sampling density is relatively high, the contaminants tend to be co-located in the EW, and the remediation footprint covers most of the EW. Consistent with other sediment cleanups, these uncertainties are addressed in two ways:

- As described in Appendix F of the FS, an additive design factor has been applied to better estimate the volume of contaminated sediment assumed to require removal. Any additional volume derived from the IDW interpolation area outside of the Thiessen polygon area will be accounted for in this factor, so adding that area becomes unnecessary. This approach has been acceptable to EPA in the past and accounts for additional volume removed following dredge prism design as a result of the following components (Palermo 2009):
  - Refining horizontal limits that require removal (from additional sediment characterization during design)
  - Additional volume for constructability of dredge prisms, such as stable side slopes
  - Allowable overdredge thickness
- Additional surface sediment characterization is likely to be conducted during remedial design in order to more accurately delineate the boundaries of areas with contaminants above RALs that will require remediation. Further boundary delineation may result in expanding or contracting the limits of required remediation. However, for purposes of FS evaluation, refinement of the remedial boundaries is not considered necessary in order to assess remedial alternatives.

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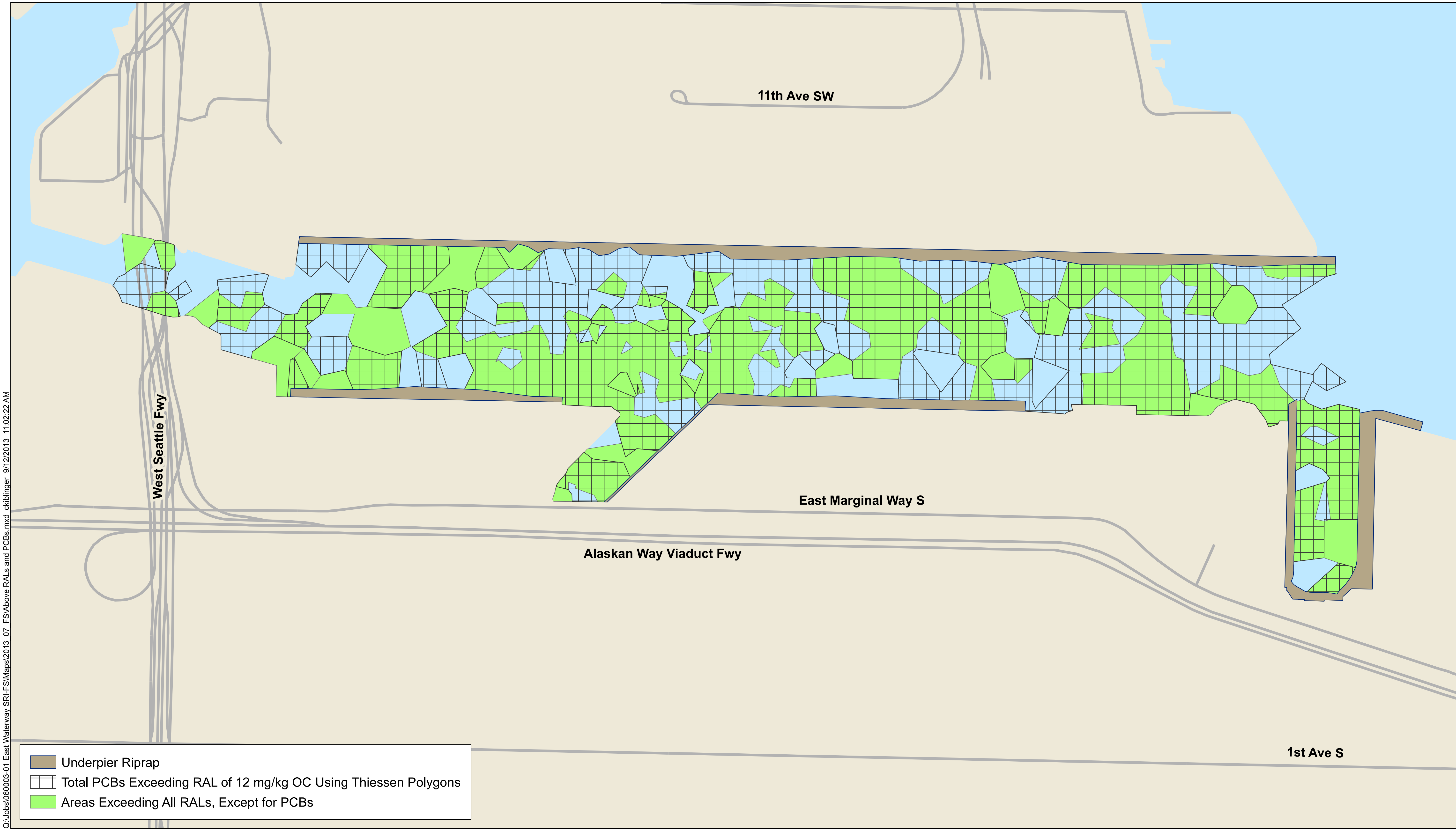
FIGURES



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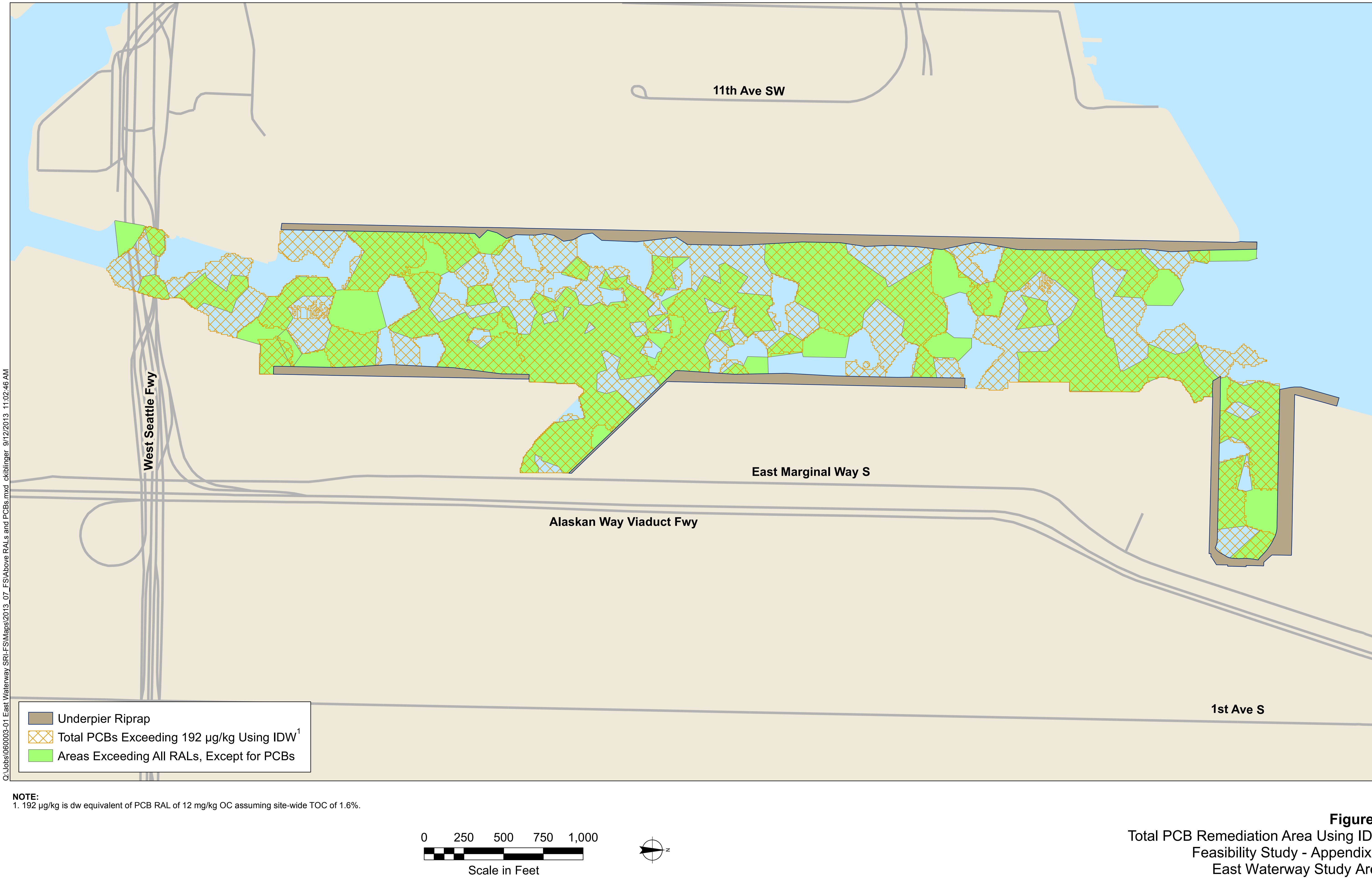
Scale in Feet

Figure 1

Total PCB Remediation Area Using Thiessen Polygons

Feasibility Study - Appendix C

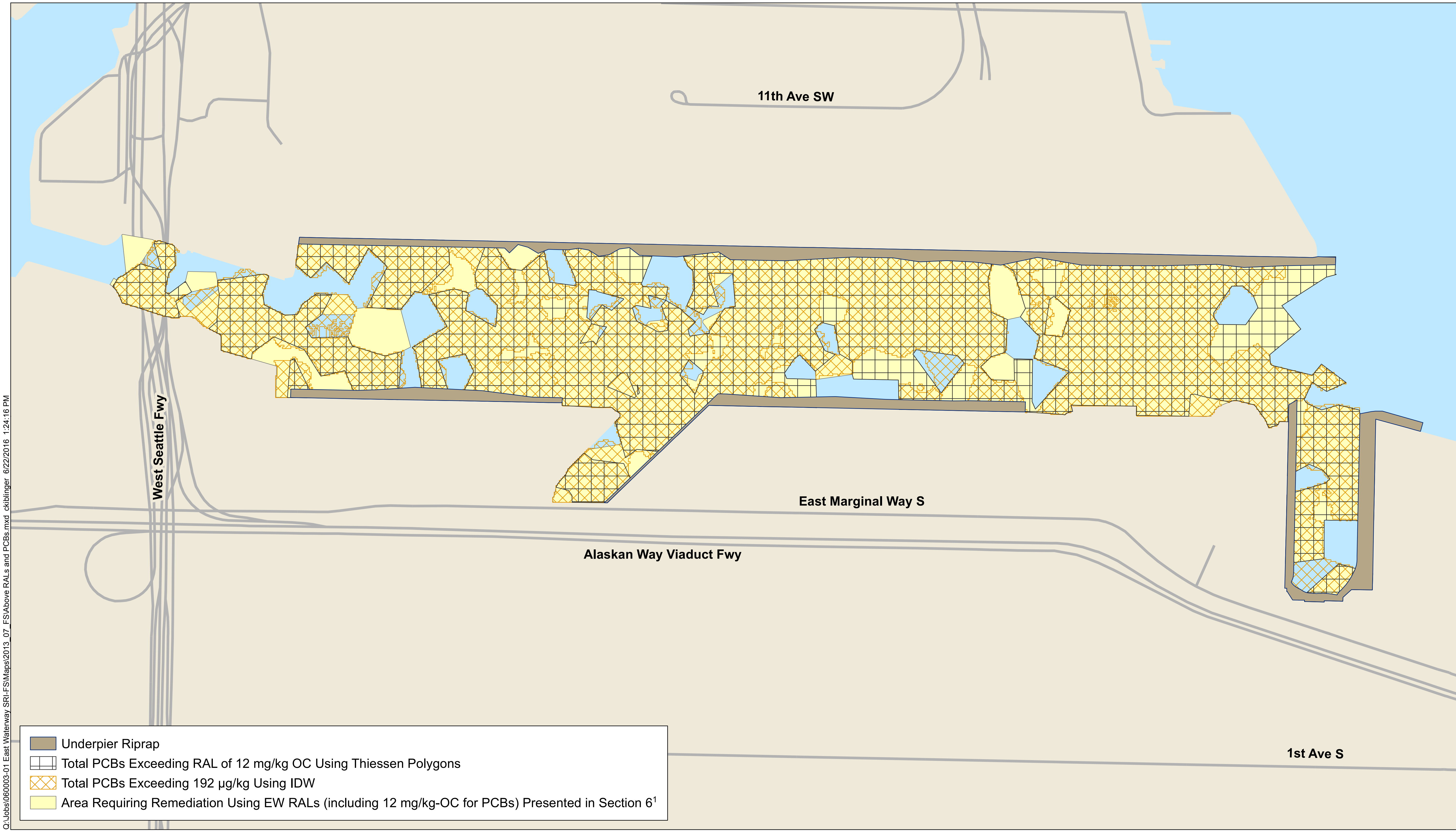
East Waterway Study Area



Q:\Jobs\060003-01 East Waterway SRI-FS\Maps\2013_07_FS\Above RALs and PCBs.mxd ckiblinger 9/12/2013 11:02:46 AM

NOTE:
1. 192 µg/kg is dw equivalent of PCB RAL of 12 mg/kg OC assuming site-wide TOC of 1.6%.

Figure 2
Total PCB Remediation Area Using IDW
Feasibility Study - Appendix C
East Waterway Study Area



Q:\Jobs\060003-01 East Waterway SRI-FS\Maps\2013_07_FS\Above RALs and PCBs.mxd ckiblinger 6/22/2016 1:24:16 PM

NOTE:
1. Includes total PCBs; total PCB RAL is 12 mg/kg OC.

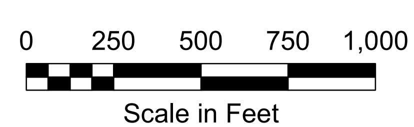


Figure 3
Potential Remediation Areas Based on Different PCB Interpolation Methods
Feasibility Study - Appendix C
East Waterway Study Area

ATTACHMENT 1
IDW MEMORANDUM

ANCHOR QEA

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MEMORANDUM

To:	Ravi Sanga, EPA	**Date:**	January 31, 2014
From:	Dan Berlin and Erik Pipkin, Anchor QEA on behalf of Port of Seattle	**Project:**	060003-01.101
cc:	Doug Hotchkiss, Port of Seattle Jeff Stern and Debra Williston, King County Pete Rude, City of Seattle		
Re:	Selection of East Waterway Inverse Distance Weighted Interpolation Parameters		

This memorandum describes the analysis conducted to select optimized interpolation parameters for calculating an inverse distance weighted (IDW) interpolated surface for total polychlorinated biphenyls (PCBs) within the East Waterway Study Area (EW). The methodology for optimizing IDW interpolation parameters for the EW is based on the process described in a memorandum prepared for the Lower Duwamish Waterway Feasibility Study (LDW Memo; LDWG 2007). The process presented in that memorandum varied the circular search radius and power for multiple IDW interpolated surfaces. Using this process, 18 IDW surfaces for total PCBs were created for the EW using the same range of input values for circular search radius and power as specified in the LDW Memo. Errors for each surface were then calculated in the same manner as in the LDW Memo using tools within ESRI's ArcGIS software.

The process for selection of optimized IDW interpolation parameters for the EW was conducted using components of the Feasibility Study (FS) dataset that will be used to select areas that require active remediation. Specifically, point data used to create IDW surfaces included samples from the entire study area with PCB results in surface sediment (0 to 10 centimeters [cm]) and shallow subsurface sediment (0 to 2 feet), which included the maximum result for sediment core samples in the upper 2 feet below mudline north of the Spokane Street Bridge. Also included in the query were 0- to 10-cm samples collected following dredging in 2005 in the Phase 1 removal area prior to placement of clean cover material.

ESRI's ArcGIS Geostatistical Analyst (GA) was used to create the IDW surfaces using the input parameters for circular search radius and power fixed to the values shown in Table 1. Consistent with the method used in the LDW Memo, the maximum/minimum number of closest samples used for grid-cell interpolation was varied between 1/1 and 10/1. Cell size was set at 10 feet, and mean higher high water (MHHW) was used as an input barrier to prevent interpolation between areas separated by dry land.

In order to evaluate the errors of each parameter set, both a GA layer and an ESRI grid were created. The cross-validation tool available within GA was used to calculate the mean error and the root mean square error (RMSE).

The mean error can be defined as the averaged difference between the measured and predicted values and calculated by the equation below.

$$\frac{\sum_{i=1}^{n}\left(\hat{Z}(s_i) - z(s_i)\right)}{n}$$

where:

n	=	number of points
$\hat{Z}$	=	measured value
z	=	predicted value
s	=	value
i	=	point number

The RMSE is the square root of the averaged squared difference between the measured and predicted values and determined by the equation below.

$$\frac{\sqrt{\sum_{i=1}^{n}\left(\hat{Z}(s_i) - z(s_i)\right)^2}}{n}$$

where:

n	=	number of points
$\hat{Z}$	=	measured value
z	=	predicted value
s	=	value
i	=	point number

Cross-validation calculates error by omitting a point from the input, calculating the interpolated value using the remaining points, and then comparing the interpolated value to the measured value. This is conducted for each point in the dataset to determine the mean error and RMSE. In addition, a point table was exported for each IDW from GA, which included the measured and interpolated value for each point, and was subsequently used to calculate the mean absolute error.

In addition to the cross-validation errors, an observed RMSE was also calculated. The observed RMSE was calculated in the same manner as in the LDW Memo and was used along with the RMSE to identify the optimized set of interpolation parameters. Observed RMSE is calculated using the same RMSE equation; however, points are not iteratively removed. Rather, the difference between the measured and predicted values at each point location is used. Results may differ from the CV RMSE if individual data points are not spatially coincident with the IDW raster cells, which is a function of the point distribution and raster cell size and extent. To facilitate the calculation of observed RMSE, a simple process was built within ArcGIS Model Builder to automate the geoprocessing.

Consistent with the process described in the LDW Memo, the lowest RMSE and observed RMSE were the key statistical metrics used to identify the optimized set of parameters for IDW interpolation in the EW. The parameter combination with the lowest RMSE has the lowest dataset variability. RMSE decreases as the search radius increases and as the power decreases (within each search radius group). The IDW interpolation with the lowest observed RMSE results in the lowest error based on a comparison of measured versus predicted values. Based on these metrics, parameters for IDW interpolation using the EW FS dataset are optimized with a power of 1 and circular search radius of 75 feet, as indicated in Table 1.

Table 1
Interpolation Parameters Tested for Total PCBs – East Waterway

Power	Circular Search Radius (feet)	Cross Validation			Observed RMSE
		Mean Error	Mean Absolute Error	RMSE	
1	250	57.3	714.4	1260	675
2	250	76.3	750.7	1351	666
3	250	80.2	766.6	1406	728
4	250	80.8	776.2	1438	793
5	250	81.2	784.5	1456	851
10	250	86.6	809.8	1506	1000
1	150	99.0	811.9	1432	670
2	150	106.6	826.9	1487	666
3	150	105.8	829.3	1519	728
4	150	103.6	830.0	1536	793
5	150	101.8	832.0	1547	851
10	150	101.7	841.5	1578	1000
1	75	94.9	878.0	1625	648
2	75	95.7	878.3	1636	666
3	75	95.3	878.8	1638	728
4	75	95.2	872.8	1640	793
5	75	95.6	873.0	1642	851
10	75	100.5	876.6	1656	1000

Notes:
1. A maximum of 10 and a minimum of 1 "nearest neighbor" data points were used in all interpolations.
2. Cell size for all interpolations is 10 feet.
3. Lowest Observed RMSE occurs with power of 1 and circular search radius of 75 feet (shaded).

PCB – polychlorinated biphenyl
RMSE – root mean square error

REFERENCES

LDWG (Lower Duwamish Waterway Group), 2007. Draft Memorandum: Updated Methodology for Interpolating Surface Sediment Chemistry in the Lower Duwamish Waterway Feasibility Study. Prepared by RETEC. December 11.

APPENDIX D – CAP MODELING
EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

Prepared for
Port of Seattle

Prepared by
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June 2019

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1 INTRODUCTION

Capping is a remedial technology component of all active remedial alternatives being developed and evaluated for cleanup of contaminated sediments in the East Waterway (EW) Operable Unit (OU). Gaining a Feasibility Study (FS)-level understanding of how this technology is expected to perform under conditions within the EW OU is an essential consideration in assessing its technical feasibility and effectiveness. One key consideration to be addressed during design is the potential for contaminants originating from buried sediments or groundwater to emerge through the cap into the biologically active zone (BAZ) and overlying water column (i.e., by diffusion and groundwater advection) at levels that constitute an unacceptable risk. To this end, porewater contaminant concentrations within a hypothetical sediment cap were modeled and are presented in this appendix.

2 MODEL SELECTION AND TECHNICAL APPROACH

A one-dimensional steady state model (version 1.19, 2012) developed by Lampert and Reible (2009) for chemical transport within sediment caps was used for the chemical isolation evaluation. This model simulates the time-variable fate and transport of chemicals (dissolved and sorbed phases) through the processes of advection, diffusion, dispersion, biodegradation, bioturbation/biodiffusion (in the biologically active zone), and exchange with the overlying surface water. This model is consistent with U.S. Environmental Protection Agency and U.S. Army Corps of Engineers guidance for cap design (Palermo et al. 1998a, 1998b). The model is a spreadsheet analysis and, therefore, easily manipulated for investigating various scenarios consistent with an FS-level analysis. This model has been used for cap evaluations for other contaminated sediments sites, including the Lower Duwamish Waterway (LDW; AECOM 2012), and for cap design at numerous sites across the United States. The model was used to evaluate total polychlorinated biphenyls (PCBs) and mercury in the EW OU because they are key contaminants of concern at the site with different properties affecting transport. In addition, the analysis for PCBs can be generalized to be representative of other hydrophobic organic compounds, such as carcinogenic polycyclic aromatic hydrocarbons (cPAHs) and dioxins/furans (Section 5.2). Additional contaminants may be evaluated during design.

3 INPUT PARAMETERS

Model input parameters are listed in Table 1. Each parameter has a best-estimate value, and low and high values were identified for select parameters. The best-estimate parameter values represent the best-estimate of conditions in the EW OU. The low and high values represent the uncertainty in conditions occurring in the EW OU based on uncertainty in parameter estimates or variability in site conditions. The basis for each parameter value is listed in Table 1, and several important input parameters are discussed in the text of this section.

The Lampert and Reible (2009) spreadsheet model uses porewater concentration within the sediments below the cap as a boundary condition (constant concentration is conservatively assumed, which results in an infinite source assumption). Limited porewater data were available to characterize the EW OU; therefore, the porewater boundary concentration beneath the cap was computed based on measured contaminant concentrations in bulk sediment and the equilibrium partitioning coefficient (K_d).

The model was set up for evaluation of organic compounds for which the K_d is assumed to equal the chemical's organic carbon partition coefficient (K_{oc}) times the fraction of organic carbon (f_{oc}). However, for metals, the K_d is assumed to be constant with f_{oc}. Therefore, to run the model for mercury, the f_{oc} and K_{oc} values were input so that the model would run at the appropriate K_d value.

The FS assumes that the cap would be 5 feet thick to account for 1.5 feet of armor stone, 1 foot of filter material, and 2.5 feet of isolation material. However, the thickness of the cap was assumed to be 2 feet in the model, to approximate the minimum thickness of the isolation layer in the cap. This is very conservative because the isolation thickness would be more than 2 feet in most locations, and because the filter layer would provide more attenuation than just the isolation layer (i.e., the added separation distance associated with the armor and filter layers would reduce the concentration gradient and thereby reduce diffusive transport) and retard the flux of contaminants (i.e., especially if the layers contain any total organic carbon). Thinner cap layers may be appropriate in some locations, depending on actual contaminant concentrations, erosion protection requirements, and the composition of the isolation layer (i.e., addition of cap amendments).

The concentration of contaminated sediment underlying the cap (i.e., source concentration) will vary by location. For this analysis, three values were considered for the concentration under the cap. These are 1) the maximum concentration of samples underlying the proposed capping areas for any alternative in the FS, 2) the average of samples underlying capping areas, and 3) the assumed concentration of dredge residuals (almost all locations would undergo partial dredging prior to capping). These values are presented in Table 1; only the maximum concentrations were carried forward in the modeling as a conservative approach.

Based on the behavior of the Lampert and Reible (2009) model (e.g., see the sensitivity analysis in Appendix C, Part 8 of the LDW FS [AECOM 2012]), the following four parameters were identified as key factors to be varied in the scenario analysis:

- Partitioning/distribution coefficient
- Groundwater flow (Darcy velocity)
- Sedimentation rate (depositional velocity)
- Fraction of organic carbon in the cap material (for PCBs only)

4 SELECTION OF OUTPUT PARAMETERS AND EVALUATION CRITERIA

The model output used in this analysis is referred to as the "characteristic time to ~1% of steady-state." This output represents an approximation of the time at which 1% of the steady-state concentration at the top of the cap's chemical isolation layer (i.e., the base of the BAZ) would be reached. One percent of the steady-state concentration is not necessarily of interest to this analysis, because the time to reach steady state for sorptive contaminants such as PCBs and mercury can be hundreds or even thousands of years. However, this output parameter provides a surrogate for the time that contamination would be expected to "break through" the cap and was, therefore, deemed appropriate for an FS-level analysis. For this analysis, 100 years was considered a reasonable breakthrough time for the sediment cap effectiveness evaluation; breakthrough time less than 100 years was considered ineffective, and breakthrough time greater than 100 years was considered effective. One hundred years is considered a reasonable design life for a sediment cap given the conservatism of model parameters, the potential to refine the cap during design, and cap monitoring and maintenance activities following construction. This analysis does not focus on outputs after the 100-year evaluation threshold because waterway conditions, site use, and knowledge and practices in sediment remediation are likely to change in the next century, and because uncertainty in model inputs and calculations are compounded through time.

5 RESULTS

5.1 Scenarios

The scenarios include a total of 16 model runs as shown on Table 2: four model runs for intertidal capping areas and four model runs for subtidal capping areas, for both PCBs and mercury. Scenario 1 uses the best-estimate input parameters, and is representative of the best-estimate of conditions in the EW OU. In all four cases for Scenario 1 (intertidal/subtidal, PCBs/mercury), there is no breakthrough predicted through the cap; therefore, the isolation layer of the cap is anticipated to be effective beyond the 100-year assumed design life (and actually in perpetuity).

Scenarios 2 through 4 included variation of key parameters as a sensitivity analysis; the partitioning coefficient, Darcy velocity, and net sedimentation rate were individually varied in Scenarios 2, 3, and 4, respectively. The parameters were varied in each of these scenarios so as to decrease contaminant breakthrough time (i.e., less sorption, faster groundwater flow, and no sedimentation, respectively). For PCBs intertidal Scenarios 2 and 4, the model predicted breakthrough is prior to the 100-year benchmark, with an f_{oc} in the cap of 1%. Therefore, as shown in Table 2a, the f_{oc} has been adjusted for these scenarios until the design life equals 100 years. The level of organic carbon predicted to be required in these scenarios is reasonable and has been demonstrated to be attainable and effective on similar sediment caps using organic carbon or other material (such as activated carbon), if determined to be necessary during remedial design.

For PCBs in the subtidal areas and for mercury in both intertidal and subtidal locations, breakthrough for Scenarios 2 through 4 was not predicted to occur prior to the 100-year benchmark, indicating that a 2-foot isolation layer is likely to be effective.

5.2 Generalizing the Results for Other Organic Contaminants

The results of this analysis for total PCBs can be generalized to apply to other organic compounds that have K_{oc} values similar to, or greater than, total PCBs (i.e., that migrate at a similar or slower rate than PCBs). This includes cPAHs and dioxins/furans. Table 3 shows the K_{oc} values for PCBs, PAHs, and dioxins/furans for comparison. Compounds with K_{oc} values higher than those used in this analysis will migrate more slowly than PCBs and, therefore, a 2-foot isolation layer is likely to be effective over the 100-year evaluation period. Compounds with lower K_{oc} values than those used in this analysis will migrate more quickly than PCBs; other compounds will be evaluated as necessary in remedial design during location-specific capping evaluations.

5.3 Conclusions

This analysis indicates that a 2-foot cap isolation layer thickness is a reasonable assumption for the EW OU FS. This thickness is predicted to meet performance goals under the best estimate of waterway conditions, even with multiple conservative assumptions being used for modeling, such as ignoring the attenuation benefits provided by the cap filter and armoring layers, and modeling the maximum concentration measured in potential capping areas. For two hypothetical conditions in intertidal areas, the fraction of organic carbon would need to be specified at minimum levels (e.g., 1.3% organic carbon in the worst-case scenario) to meet performance criteria. The final cap isolation layer thickness and composition will be determined during remedial design based on additional testing and analysis.

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TABLES

Table 1
Input Values

Parameter	Units	Input Value(s) Best Estimate	Low[a]	High[a]	Basis
Contaminant Properties					
Organic carbon partition coefficient for PCBs, log K_{oc}	log L/kg	5.91	5.0	6.5	Based on MTCA and Mackay et al. (2006), consistent with LDW assumptions (AECOM 2012)
Partition coefficient for PCBs, K_d	L/kg	calculated	calculated	calculated	$K_d = 10^{(\log K_{oc})} \times f_{oc(bio)}$ for organic compounds
Partition coefficient for mercury, log K_d	log L/kg	4.9	3.8	6.0	Mean, low, and high values of 2 values for sediment partitioning in Allison and Allison (2005)
Colloidal organic carbon partition coefficient	log L/kg	calculated	calculated	calculated	$\log K_{doc} = \log K_{oc}-0.37$ (Lampert and Reible model [2009] default). Used for PCBs but not Hg
Water diffusivity	cm^2/s	5.0×10^{-6}	n/a	n/a	Consistent with LDW assumptions (AECOM 2012)
Cap decay rate	yr^{-1}	0	n/a	n/a	Conservatively assume no degradation
Bioturbation layer decay rate	yr^{-1}	0	n/a	n/a	Conservatively assume no degradation
Contaminant concentration in sediment	µg/kg dw (PCBs)	7,600 µg/kg dw	n/a	n/a	Maximum concentration from samples underlying the capping area for any FS alternative: 7,600 µg/kg dw; conservatively use this maximum value for all scenarios for this FS-level evaluation
	mg/kg dw (Hg)	2.5 mg/kg dw	n/a	n/a	Maximum concentration from samples underlying the capping area for any FS alternative: 2.5 mg/kg dw; conservatively use this maximum value for all scenarios for this FS-level evaluation
Contaminant porewater concentration	µg/L	calculated	calculated	calculated	$C_{0(pw)} = C_{0(sed)}/K_d$
Sediment Properties					
Biological active zone fraction organic carbon	%	1.6%	n/a	n/a	1.6% based on conditions in the EW OU (FS Section 2)
Colloidal organic carbon concentration	mg/L	2	n/a	n/a	Consistent with LDW assumptions (AECOM 2012). Sorption to porewater dissolved organic matter not simulated for mercury
Intertidal Darcy velocity, *(positive is upwelling)*	cm/yr	3,200	1,000	11,000	Based on EW SRI Section 2.6.1 (Windward and Anchor QEA 2014). Darcy velocity = porewater velocity x porosity
Subtidal Darcy velocity *(positive is upwelling)*	cm/yr	250	106	590	Based on Fabritz et al. (1998); site-specific information has not been collected. Groundwater flux is lower in deeper areas in the Duwamish Basin compared to shallow intertidal areas, but additional information may be required during design
Net sedimentation rate$_p$	cm/yr	1.2	0	1.8	0 to 1.8 cm/yr based on conditions in the EW OU (FS Section 2). Best estimate and high values are consistent with those determined for site-wide predictive modelling (see Section 5.1.2). Low value set equal to 0 for a location-specific potential minimum value as a worst-case scenario [b]
Bioturbation layer thickness	cm	10	n/a	n/a	10 cm is the bioturbation layer thickness for all areas of the EW OU; cap thickness would also be designed to protect for additional thickness in clamming areas (25 cm)
Porewater biodiffusion coefficient	cm^2/yr	100	n/a	n/a	Typical/recommended value Reible (2012)
Particle biodiffusion coefficient	cm^2/yr	1	n/a	n/a	Typical/recommended value Reible (2012)
Cap Properties					
Cap thickness (isolation layer)	ft	2	n/a	n/a	Assume 2-foot chemical isolation layer that could be modified during design; conservatively assume filter and armor layers provide no chemical isolation/ attenuation
Cap materials – Granular (G) or Consolidated Silty/Clay (C)	--	G	n/a	n/a	Assume granular cap
Cap consolidation depth	cm	0	n/a	n/a	Assume no consolidation (typical for sand)
Underlying sediment consolidation due to cap placement	cm	23	n/a	n/a	Consistent with LDW assumptions (AECOM 2012) and EW conditions
Porosity	--	0.4	n/a	n/a	Typical value for sand
Particle Density	g/cm^3	2.6	n/a	n/a	Typical value for sand
Fraction organic carbon, *(f_{oc})*	%	1%	n/a	variable	Value represents sorptive capacity of cap for organics; can be modified during remedial design

Notes:

a. Results of model runs for sensitivity inputs values are not presented in Table 2 if they do not provide additional information. For example, the best estimate conditions predict no contaminant breakthrough; therefore, model runs with high K_{oc} values would also result in no contaminant breakthrough and are not shown. However, all sensitivity values are presented in this table for completeness.

b. The range of average site-wide net sedimentation rates used in the box model is 0.5, 1.2, and 1.8 cm/yr. A low-end net sedimentation rate of 0 cm/yr is used for cap modeling to represent a worst-case scenario that may occur in localized capping areas.

% – percent
µg/kg – microgram per kilogram
µg/L – microgram per liter
cm – centimeter
cm/yr – centimeter per year
cm^2/s – square centimeter per second
dw – dry weight
EW – East Waterway
f_{oc} – fraction of organic carbon
FS – Feasibility Study
ft – feet
g/cm^3 – gram per cubic centimeter
Hg – mercury
K_d – equilibrium partitioning coefficient
K_{oc} – organic carbon partitioning coefficient
L/kg – liter per kilogram
LDW – Lower Duwamish Waterway
log – logarithm
mg/kg – milligram per kilogram
mg/L – milligram per liter
MTCA – Model Toxics Control Act
n/a – sensitivity not run for parameter
OU – Operable Unit
PCB – polychlorinated biphenyl
SRI – Supplemental Remedial Investigation
yr^{-1} – per year

Table 2a
Cap Model Results for PCBs

	Scenario	Cap Isolation Layer Thickness (feet)	log K_{oc} (log L/kg)	Darcy Velocity (cm/yr)	Net Sedimentation Rate (cm/yr)	Cap f_{oc} (%)	Characteristic Time to ~1% of Steady State (Time to Breakthrough [years])
		Select Input Parameters					Output Parameter
Intertidal							
1	Best-estimate conditions	2	5.9	3,200	1.2	1.0%	No Breakthrough
2	Best-estimate conditions with low K_{oc}; f_{oc} varied to achieve 100-year design life		5.0	3,200	1.2	1.6%[a]	100
3	Best-estimate conditions with high Darcy velocity		5.9	11,000	1.2	1.0%	No Breakthrough
4	Best-estimate conditions with no sedimentation; f_{oc} varied to achieve 100-year design life		5.9	3,200	0.0	1.1%[a]	100
Subtidal							
1	Best-estimate conditions	2	5.9	250	1.2	1.0%	No Breakthrough
2	Best-estimate conditions with low K_{oc}		5.0	250	1.2	1.0%	No Breakthrough
3	Best-estimate conditions with high Darcy velocity		5.9	590	1.2	1.0%	No Breakthrough
4	Best-estimate conditions with no sedimentation		5.9	250	0.0	1.0%	1,100

Table 2b
Cap Model Results for Mercury

	Scenario	Cap Isolation Layer Thickness (feet)	log K_d (log L/kg)	Darcy Velocity (cm/yr)	Depositional Velocity (cm/yr)	Cap f_{oc} (%)	Characteristic Time to ~1% of Capped Sediment (Time to Breakthrough [years])
		Select Input Parameters					Output Parameters
Intertidal							
1	Best-estimate conditions	2	4.9	3,200	1.2	n/a	No Breakthrough
2	Best-estimate conditions with low K_d		3.8	3,200	1.2	n/a	No Breakthrough
3	Best-estimate conditions with high Darcy velocity		4.9	11,000	1.2	n/a	No Breakthrough
4	Best-estimate conditions with no sedimentation		4.9	3,200	0.0	n/a	1,500
Subtidal							
1	Best-estimate conditions	2	4.9	250	1.2	n/a	No Breakthrough
2	Best-estimate conditions with low K_d		3.8	250	1.2	n/a	No Breakthrough
3	Best-estimate conditions with high Darcy velocity		4.9	590	1.2	n/a	No Breakthrough
4	Best-estimate conditions with no sedimentation		4.9	250	0.0	n/a	18,000

Notes:

a. f_{oc} was adjusted upward from 1% to meet a design life of 100 years.

Input values varied from the best-estimate conditions

% – percent

cm/yr – centimeter per year

f_{oc} – fraction of organic carbon

K_d – equilibrium partitioning coefficient

K_{oc} – organic carbon partitioning coefficient

L/kg – liter per kilogram

log – logarithm

n/a – not applicable

PCB – polychlorinated biphenyl

Table 3
K_{oc} Values for Select Organic Compounds

Compound	Log K_{oc}
PCBs	
Modeled values for this analysis	**5.0, 5.91, 6.5**
PCB-Aroclor 1016	5.04[a]
PCB-Aroclor 1260	5.91 [a]
PCBs (generic mixture)	5.49 [a]
cPAHs	
Benzo[a]anthracene	5.56 [a]
Benzo[a]pyrene	5.99 [a]
Benzo[b]fluoranthene	6.08 [a]
Benzo[k]fluoranthene	6.08 [a]
Chrysene	5.60 [a]
Dibenz[a,h]anthracene	6.26 [a]
Indeno[1,2,3-cd]pyrene	6.54 [a]
cPAH weighted average based on TEQ	6.02
Dioxins/furans	
TCDD; 2,3,7,8-	6.7[b]

Notes:
a. From Washington State Department of Ecology Cleanup Levels and Risk Calculation Database (CLARC), accessed July 2013.
b. Average of values listed in Mackay et al. (2006).
cPAH – carcinogenic polycyclic aromatic hydrocarbon
K_{oc} – organic carbon partitioning coefficient
Log – logarithm
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

ATTACHMENT 1
CAP ARMOR EVALUATION

1 METHODOLOGY TO EVALUATE STABLE SEDIMENT GRAIN SIZE DUE TO VESSEL ACTIVITY

Bed sediments in the East Waterway (EW) are subject to current velocities due to tidal and riverine currents and intermittent high velocities due to vessel activity (propeller wash, or propwash). Engineered caps proposed for the EW need to be sized such that they remain stable under these velocities.

An evaluation was conducted as part of the EW Sediment Transport Evaluation Report (STER) to calculate the near-bed velocities caused by tidal/riverine currents and propwash (Anchor QEA and Coast & Harbor Engineering 2012). Based on the results of this evaluation, bed velocities due to propwash were found to be significantly higher than those due to riverine and tidal currents (even at the 100-year flow). Therefore, the stability evaluation of proposed engineered caps used predicted velocities from the propwash modeling to estimate a stable grain/rock size for each operational area in the EW.

Bottom velocities were calculated for various operational areas and vessels. The operational areas were established based on interviews and personal conversations with organizations, agencies, and companies that operate vessels within the EW (see Section 5.1.2 of the STER; Anchor QEA and Coast & Harbor Engineering 2012). The bottom velocities were calculated based on the appropriate vessels and operations taking place in each operational area. Figure 1-1 shows operational areas.

The stable sediment size for each operational area was calculated using an equation established by Blaauw et al. (1984). This method assumes zero movement of the sediment/rock under the applied velocity. This method requires inputs of maximum bottom velocity, gravitational constant, stone and water unit weights, and an experimentally developed constant that is dependent on the amount of sediment movement allowable.

$$V_{bmax} = C_3\left(g\ddot{A}D_{50}\right)^{1/2} \qquad 1$$

Where:

V_{bmax}	=	maximum bottom velocity
C_3	=	experimentally developed constant that was found to be 0.55 for no movement and 0.70 for small transport; 0.55 was used for this evaluation
$\ddot{A}$	=	$(a_s-a_w)/a_w$; where a_s is the unit weight of stone and a_w is the unit weight of water
g	=	gravitational constant
D_{50}	=	represents the median diameter where 50% of the material is finer based on the total weight of the sample

The equation is used to estimate the median diameter (D_{50}) that would be stable under the representative near-bed velocity due to propwash.

2 RESULTS

Table 1-1 presents the maximum near-bed velocity and the corresponding stable grain size for each operational area and vessel operation scenario.

Table 1-1
Maximum Near-bed Velocity and Stable Grain Size for Operational Area and Vessel Operation Scenarios

Area[1]	Vessel[2]	Maximum Near-bed Velocity (feet/second)	D_{50} (feet)	D_{50} (inches)
Terminal 18, Berths 1 and 2 Area 1A	Scenario 2	11.4	n/a[3]	n/a[3]
Terminal 18, Berths 3 and 4 Area 1A	Scenario 5	7.1	3.2	39.3
Area 1B	Scenario 13	3	0.5	7.0
Area 1C	Scenario 13	3	0.5	7.0
Slip 36 Area 2	Scenario 6	6.5	2.7	32.9

Area[1]	Vessel[2]	Maximum Near-bed Velocity (feet/second)	D_{50} (feet)	D_{50} (inches)
Slip 27 Area 3	Scenario 8	3	0.5	7.0
South Terminal 30 Area 4A	Scenario 9	3	0.5	7.0
South Terminal 30 Area 4A	Future Conditions Scenario 15	9	n/a[3]	n/a[3]
South Terminal 30 Area 4	Scenario 9	3	0.5	7.0
Area 4B	Scenario 9	3	0.5	7.0
Area 5	Scenario 9	3	0.5	7.0
Area 6	Scenario 10	10.6	n/a[3]	n/a[3]
Area 7	Scenario 11	4.7	1.4	17.2
Area 8	Scenario 12	4.2	1.1	13.7

Notes:
1. See Figure 1-1 for areas.
2. See Section 5.1.3 of the STER for operational area and vessel scenarios that were evaluated.
3. These scenarios are outside of the range of applicability for the methodology due to proximity of propeller to the bottom.
D_{50} – median diameter
Shaded areas have caps in one or more of the proposed FS alternatives.

Stable rock sizes predicted by Equation 1 range from 0.5 feet to more than 3 feet based on the assumption of zero movement of material under applied velocities. Several scenarios were outside the predictive range of the method and would require additional numerical modeling to evaluate; however, it is anticipated that predicted stable rock sizes would be the same or larger than the maximum size predicted for the scenarios that were evaluated (approximately 3 feet).

The maximum armor rock size was not applied to cap thickness assumptions for the EW Feasibility Study (FS). The highest armor rock sizes would be required in Areas 1A (in Terminal-18 berth areas), Area 2 (Slip 36), and Area 6 (near Olympic Tug and Barge). Capping has not been selected for any of the remedial alternatives for Areas 1A and 2. An armored cap comprised of armor rock in the 3-foot range could result in a cap thickness of approximately 8 to 9 feet, depending on the filter layer thickness between the armor and the sand cover, which would require removal of all contaminated sediment in most areas of the waterway, including Area 6. In addition, placing large rock in the navigable areas of the EW could pose a hazard for vessels operating at very low tides. However, capping was retained in Area 6 because of the large variation in mudline elevation in the area and the potential to cap deeper areas in the center of the channel. Additional analysis will be necessary during design.

For the FS analysis, a single armor size for the entirety of the EW Operable Unit was estimated to have a median diameter of 7 inches based on the stable rock size estimated for the majority of the scenarios evaluated. This armor material would require a filter material with a median diameter of approximately 0.85 inches (USACE 1992) based on methodology outlined in Ahrens (1981); a filter material with a D_{50} of 1 inch has been assumed for the EW FS. Based on these armor and filter requirements and the isolation requirements discussed in the main body of this appendix, the FS assumes that the engineered cap would have a thickness of 5 feet, comprised of a 1.5-foot-thick layer of armor material with a D_{50} of 7 inches, a 1-foot-thick layer of filter material with a D_{50} of 1 inch, and a 2.5-foot-thick layer of isolation material (see main Appendix D text).

The cap design will be further refined in remedial design with additional testing and/or evaluations for specific locations. Thicker or thinner caps may be designed based on stability considerations, contaminant breakthrough considerations, habitat considerations, and the final materials selected for construction.

3 REFERENCES

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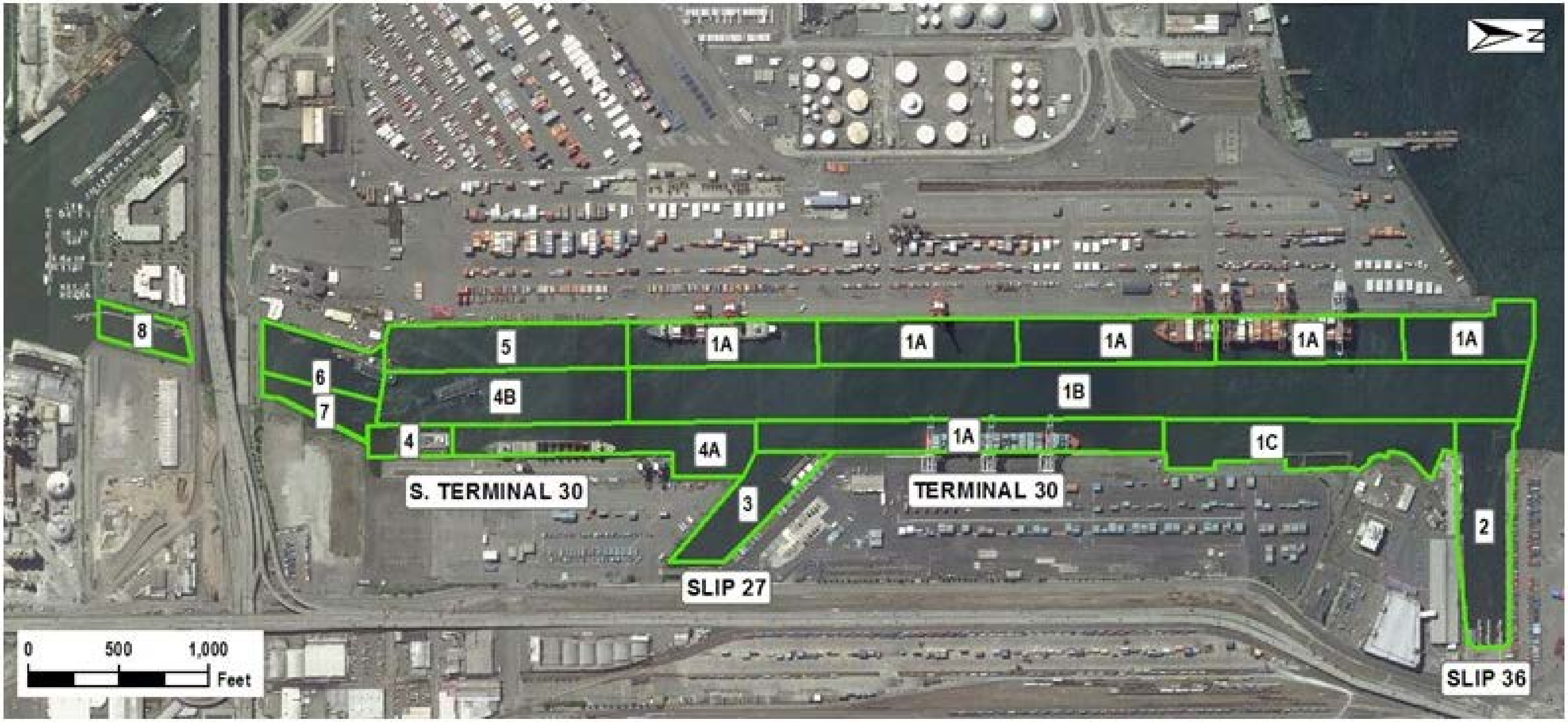
USACE (U.S. Army Corps of Engineers), 1992. Automated Coastal Engineering System (ACES). Technical Reference by D.E. Leenknecht, A. Szuwalski, and A.R. Sherlock, Coastal Engineering Center, Department of the Army, Waterways Experiment Station, Vicksburg, MS.

FIGURE



Legend

Operational Area

Figure 1-1
Operational Propwash Areas
Feasibility Study - Appendix D
East Waterway Study Area

APPENDIX E – COST ESTIMATE
EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

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TABLE OF CONTENTS

List of Tables

1 INTRODUCTION

This appendix contains information supporting the detailed remedial alternatives cost estimate prepared for the East Waterway (EW) Operable Unit (OU) Feasibility Study (FS). The cost estimate was developed in accordance with the U.S. Environmental Protection Agency (EPA) guidance document *A Guide to Developing and Documenting Cost Estimates during the Feasibility Study* (EPA 2000), and is consistent with estimates prepared for other similar feasibility studies and construction bids for projects similar to the EW.

This cost estimate provides a common basis for comparing the remedial alternatives in the FS and provides a reasonable estimate of anticipated project costs. This appendix summarizes the primary cost assumptions used to complete the estimates for all alternatives, including background on methodology (Section 2), assumptions for estimating construction timeframes (Section 3), a summary of the estimated costs for remedial alternatives (Section 4).

The FS cost estimate contains six tables that are organized as follows:

- Table 1 provides the unit costs for each line item used in the cost estimate and a summary of the basis for each.
- Table 2 presents the production rates and daily cost assumptions behind the unit costs estimates for dredging and placement activities.
- Table 3 presents the monitoring and sampling costs for the alternatives based on the monitoring quantities in Appendix G.
- Table 4 presents the assumption for the construction timeframe calculation for the alternatives.
- Table 5 presents the quantities and costs for the alternatives.
- Table 6 provides an overall summary of the total cost for each alternative.

2 COST ESTIMATING METHODS AND ASSUMPTIONS

The cost estimate was developed by determining the cost items associated with remediation for each of the remedial alternatives, estimating unit costs for these items, and multiplying these unit costs by quantities for each alternative. In developing unit costs, a number of assumptions were made to define the scope of particular unit costs; Table 1 presents the unit costs and the basis for each. The following sources of information were used to estimate unit costs:

- Bids and construction estimates for recent sediment remediation projects
- Best professional judgment based on past experience with similar remedial actions and associated pricing
- Local marine contractor input

In particular, this cost estimate draws heavily from review of recent bid and estimate costs in the greater Pacific Northwest region, where a number of similar sediment remediation projects are currently, or were recently, in design or under construction. Unit costs in Table 1 rely primarily on review of the projects in the following bullets, with the final unit cost determined using the best professional judgement of remediation engineers with knowledge of the EW site. Citations are included for sites with publicly available cost information.

- Lower Duwamish Waterway Feasibility Study. Duwamish River, Seattle, Washington (AECOM 2012)
- Jorgenson Forge Sediment Remediation. Duwamish River, Seattle, Washington (Anchor QEA project experience)
- Slip 4 Early Action Area Cleanup. Duwamish River, Seattle, Washington
- Puget Sound Naval Shipyard Activated Carbon Sediment Amendment Installation. Sinclair Inlet, Bremerton, Washington (Johnston et al. 2013)
- Port of Seattle Terminal 18 (T-18) Maintenance Dredging Project. Seattle, Washington (Anchor QEA project experience)
- Port of Bellingham Whatcom Waterway Remediation. Bellingham Bay, Bellingham, Washington (Anchor QEA project experience)
- Port of Olympia Interim Action Marine Terminal Berth Remediation. Budd Inlet, Olympia, Washington (Anchor QEA project experience)

- Former Scott Mill Sediment Remediation. Anacortes, Washington (Anchor QEA project experience)
- Port of Vancouver Alcoa Facility Sediment Remediation. Vancouver, Washington (Anchor QEA project experience)
- Port of Portland Terminal 4 Sediment Remediation. Lower Willamette River, Portland, Oregon (Anchor QEA project experience)
- Esquimalt Graving Dock Waterlot Remediation Project, Esquimalt Harbour, Esquimalt, British Columbia (Anchor QEA project experience)

The following sections summarize specific key assumptions used to develop individual line items or sections of the cost estimate. Table 1 provides the basis for all unit costs.

2.1 Mobilization, Demobilization, and Other Pre-construction Activities

Mobilization and demobilization include bringing equipment and personnel to the site (mobilization) or removing equipment and personnel (demobilization) to complete the remedial action. This item is assumed to include mobilization and demobilization of removal and placement operations barges, equipment preparation, transload facility, upland equipment, ancillary equipment, procedural costs, insurance, and bonding. Because the scope of unrestricted (i.e., open water) dredging is similar for all remedial alternatives, the base mobilization/demobilization costs are assumed to be the same for all alternatives.

There is currently one sediment transload facility available near the EW that is located on the Lower Duwamish Waterway (LDW); however, the availability of this transload facility is not assured in the future. This cost estimate assumes that the construction and permitting of a transload facility prior to dredging would be a reasonable, cost-effective approach for this project. This approach would also include costs prior to each construction season to maintain or remobilize the transload facility and renew permits. Tasks involved in developing a new transload facility could include land lease or land purchase, permitting, transload crane, temporary containment vault, water treatment system, amendment delivery system, container loading area (truck or rail), and rail spur or container transload area, depending on the location of the site developed for transloading. If an existing transload facility is used, then the total transload and disposal costs are expected to be similar to those in the FS cost estimate. In this case, the mobilization costs would go down because the transload facility would not need to be constructed specifically for the EW cleanup, but the unit transloading costs would go up to incorporate up-front costs to the entity owning/operating the transload facility for mobilization, permitting, and land lease.

Seasonal construction mobilization/demobilization costs were applied for each year of construction. Therefore, costs are higher for alternatives with more construction seasons. Additional mobilization/demobilization costs were applied to two specific remedial actions: underpier hydraulic dredging, and dredging under the West Seattle Bridge. Diver-assisted hydraulic dredging would require the mobilization of specialized equipment, personnel, and dewatering facilities. Dredging under the West Seattle Bridge would incur additional costs to address access from the uplands and mobilizing smaller equipment capable of working in the limited access area. These were applied to project costs on a construction-season basis (i.e., annually).

Additional pre-construction activities include the preparation of staging areas, stockpile areas, implementation of site controls, land lease, project management labor, office setup, and preparation of pre-construction submittals. These additional mobilization costs were also applied to project costs annually.

2.2 Removal

The unit costs for sediment removal (cost per cubic yard) were estimated based on the sediment removal rates (cubic yards per day) and daily costs (cost per day) associated with construction, as developed in Table 2. For the purpose of providing appropriate unit cost rates, three types of removal scenarios were considered: one for dredging in unrestricted areas (open water), one for dredging under the West Seattle Bridge, and one for diver-assisted hydraulic dredging. The costs for dredging in unrestricted areas were based on recent bids for similar work. The area under the West Seattle Bridge cannot be accessed from the water, but all equipment and materials must be mobilized from the upland. The dredging rate was calculated based on open-water dredging rates, adjusted assuming that the dredge would be used to remove contaminated sediment and to load trucks. The dredging rate also accounts for limited equipment access, limited space for maneuvering equipment, and cost for truck delivery to the transload area. The costs for diver-assisted hydraulic dredging under piers could be highly variable and were estimated based on discussions with local divers and project experience on other projects. Diver-assisted hydraulic dredging in deep water (e.g., 50 feet) is not commonly performed. Costs are difficult to estimate because there are few project examples to reference. Diver-assisted hydraulic dredging was conducted for the Esquimalt Graving Dock Waterlot Remediation Project in Esquimalt, British Columbia, in 2013 to 2014. This dredging occurred in about 20 feet of open water (not underpier). Costs were approximately $1,100/cy. Few other diver-assisted dredging projects have been recently completed in the northwest. Uncertainties around the costs for diver-assisted hydraulic dredging are driven by uncertainty in conditions under piers (e.g., debris), working durations and conditions for divers, treating large quantities of water, and effectiveness of hydraulic dredging equipment.

Water management is a key cost consideration for removal operations, as varying containment and treatment methods can significantly affect final costs and production rates. The cost estimate assumes that dewatering for mechanically dredged material (i.e., material from unrestricted dredging areas) would be performed using gravity to pass water through specified passive filter material and returning water to the dredging area. Gravity dewatering is facilitated through the use of temporary holding barges equipped with weirs or ballasts and filtration systems. Water generated during the dewatering is typically discharged to receiving waters directly after settling and filtration (see Section 7.5.1.1). This method was recently used during maintenance dredge activities for contaminated sediment along T-18 in the EW and was able to meet water quality standards. If water quality standards cannot be achieved using filtration, then alternative treatment methods will need to be considered during remedial design or construction. For the large quantities of water generated by diver-assisted hydraulic dredging, water will likely need to be treated by a water treatment system installed on a barge or in the uplands. Treated water would be returned to the waterway. Water management costs for mechanical dredging are assumed to be part of unit costs for dredging; water treatment costs for hydraulic dredging are included as a separate line item and are based on recent local construction experience and discussions with contractors, considering the conditions of the EW (e.g., deep water, the need for barge-mounted equipment).

Transloading, transportation, and disposal costs are based on recent project costs in Seattle, Washington. Transportation to the disposal facility would occur by rail car directly from the transloading facility to a facility permitted to receive contaminated sediment.

2.3 Material Placement

Material placement activities include placement materials required for engineered cap, dredging residuals management cover (RMC), dredge backfill to restore elevations in required locations, enhanced natural recovery (ENR), and in situ treatment. Unit costs for furnishing materials include costs for sand (cap isolation material, RMC, backfill, and ENR), gravel (cap filter material), cap armor (assumed to be 6-inch stone), and in situ treatment material (assumed to be a mixture of powdered activated carbon, binding material, and a substrate material such as sand or gravel). Unit costs for material acquisition are based on recent bids and discussions with local suppliers (e.g., CalPortland).

Placement of materials is assumed to occur with dredging equipment in open-water areas, and with other techniques such as a Telebelt in restricted access areas (e.g., under piers and low bridges). The assumptions used to develop the unit costs for placement are provided in Table 2 and are consistent with recent bids. Unit costs for placement in restricted areas are based on the recent underpier in situ treatment pilot study at Bremerton Naval Shipyard (Johnston et al. 2013).

2.4 Contingency, Management, Oversight, and Non-construction Costs

The assumptions for contingency, management, oversight, and non-construction costs are shown in Table 1.

EPA FS cost guidance (EPA 2000) suggests that contingency be factored into a cost estimate to cover unknowns, unforeseen circumstances, and unanticipated conditions reducing the overall risk of cost overruns. For this project, 30% has been applied to the construction costs to cover potential scope and bid contingency costs. This value is in the mid-range of the values specified in the EPA cost guidance document (EPA 2000), is a typical conceptual-level contingency for similar projects.

Pre-construction costs include remedial design (including sampling) and permitting, pre-construction baseline monitoring, project management, and agency review and oversight. Design and permitting are estimated to be 5% of the total construction costs. Pre-construction baseline sampling costs are based on the sampling scope and unit costs provided in Table 3. The basis for the monitoring scope is addressed in Appendix G. Project management is assumed to be 1% of the total construction costs, and agency review and oversight are estimated to be $500,000/year.

Indirect construction costs during construction include construction management support, environmental compliance, project management, and agency review and oversight and are estimated based on project experience and best professional judgement. Construction management support is estimated to be 10% of total construction costs. Water quality monitoring is based on estimated costs per construction day. Confirmational sampling is based on alternative-specific assumptions in Table 3. Project management is estimated to be 4% of the total construction costs, and agency review and oversight are estimated to be $500,000/year during this phase of the project.

Post-construction costs include operations and maintenance and long-term monitoring costs, costs for potential adaptive management actions (contingency remedial actions), project management, and agency review and oversight. Costs for operations and maintenance and long-term monitoring are based on alternative-specific estimates in Table 3. Costs for adaptive management are based on per-acre unit costs for remediation, roughly equivalent to dredging unit capital costs either in open-water or underpier areas. Contingency remediation is assumed to be needed in 15% of MNR, ENR, and in situ treatment areas. Project management is estimated to be 1% of the total construction costs, and agency review and oversight costs are estimated to be $120,000/year during this phase of the project (equivalent to $200,000/year during 5-year reviews and $100,000 between 5-year reviews).

3 CONSTRUCTION TIMEFRAME

Construction timeframe was calculated as part of this cost estimate to determine applicable durations for project elements (Table 4). The construction timeframe was calculated for six separate construction activities based on varying production rates, including the following:

- Removal
  - Open water (unrestricted access)
  - Limited access (under the West Seattle Bridge)
  - Underpier (diver-assisted hydraulic dredging)
- Placement
  - Open-water sand or gravel (applies to engineered cap isolation and filter layers, dredge backfill, ENR)
  - Open-water engineered cap armor layer material
  - Restricted access (underpier and low bridges; in situ treatment or ENR)
  - Open-water residual management cover (assumed to occur after dredging)

For each of these areas, the total number of construction days was calculated based on the volumes to be removed or placed for each alternative and an estimated production rate for each activity. The estimated production rates include an efficiency factor of 70% that accounts for project downtime due to weather delays, equipment maintenance or repair, water quality exceedances, or other reasons (Table 2). The total number of construction days was estimated assuming that one open-water operation, one underpier operation, and one restricted access operation would occur concurrently. Following several seasons of removal, this construction timeframe estimate assumes that placement operations (capping, ENR, or in situ treatment) would happen concurrently with dredging operations, with sufficient distance and controls to avoid contamination from dredging residuals (e.g., if dredging operations start in the south part of the site and move northward, then capping could occur in the south portion of the site while dredging occurs in the north portion of the site). However, the ability to perform concurrent operations while limiting recontamination of placed material is a source of uncertainty in this construction timeframe estimate. Finally, residuals management placement is assumed to occur following all dredging and other placement operations. Detailed phasing for the EW cleanup will be determined in remedial design.

The number of construction seasons was estimated at 100 work days per season. This corresponds to an approximate construction season (i.e., fish window) from October 1 through February 15, with holidays and weekends removed, assuming a mix of 5- and 6-day work weeks (12-hour days) to allow some contractor flexibility. Estimated construction times range from 8 to 12 years for the alternatives.

If the construction season was expanded to the Elliott Bay in-water construction window that formally applies in the EW from July 16 to February 15, the upper end of the number of work days in a construction season could increase up to around 150 days per season; however, the construction rate is expected to be slower during this time due to potential delays from active tribal fisheries. The extended construction window is estimated to reduce the total number of years of construction by about two construction seasons, consistently across the action alternatives (Table 4). Reducing the number of construction years has a small impact on costs because the number of total construction days would remain unchanged. Annual costs (e.g., annual mobilization and demobilization) would be reduced by about 20%, and all other costs would remain the same.

4 SUMMARY AND ACCURACY

Table 5 presents the detailed costs and Table 6 summarizes the total costs for the remedial alternatives. Costs for the action alternatives range from approximately $256 to $435 million, and are provided in 2016 dollars. Total costs include all contractor costs to complete construction, sales tax, contingency, and allowances for engineering design, permitting, construction monitoring, and agency review.

The *Guide to Developing and Documenting Cost Estimates during the Feasibility Study* (EPA 2000) recommends that a discount rate of 7% be used for estimating the net present value of cleanups conducted by non-federal parties. The present value is the amount of money that would need to be set aside at an initial point in time so that funds for implementing cleanup would be available in the future. The real discount rate approximates the marginal pre-tax rate of return on average investment adjusted to eliminate the effect of expected inflation. The net present value costs are not appropriate for the EW cleanup for the following two reasons:

1. First, three of the potentially responsible parties are public entities and have different capital costs than the private sector. Public entities may not be able to set aside sufficient funds for investment without incurring additional costs of bonding or borrowing and, therefore, would not be able to take advantage of the interest accumulation assumption implied by the net present value calculation.
2. Second, the lending environment has changed significantly since the EPA guidance was published in 2000. The current recommendations in the Office of Management and Budget Circular A-94 Appendix C, revised November 2016, indicates that the discount rate ranges from -0.5% for a 3-year investment to 0.7% for a 30-year investment.

Because many of the entities involved in the EW cleanup are public and the current discount rate is low, a 0% discount rate is appropriate to use for comparing the EW remedial alternatives in this FS. This approach is consistent with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance that allows for calculation of project-specific net present value calculations. In this case, the net present value cost is equal to the non-discounted cost (0% discount rate).

The costs provided represent the best estimate total costs for the proposed EW remedial alternatives. The major uncertainties between the cost estimate and the eventual actual cleanup costs include the following:

- Changes in the scope of cleanup due to additional characterization (e.g., changes to dredging volume)
- Changes in the scope of cleanup due to changes in remedial approach or adaptive management (e.g., ENR is considered viable in a larger area)
- Changes in unit costs due to changes in acceptable remediation practices (e.g., changes to dewatering or transloading practices)
- Changes in unit costs due to changes in economic conditions (e.g., cost of fuel, availability of contractors)
- Changes in unit costs due to changes in the rate of construction (e.g., additional delays from working around shipping vessels, or tribal fishing vessels associated with salmon runs. The latter may trigger additional standby costs if work is halted entirely while tribal fishing is conducted within the EW)
- Additional costs that were not considered for this FS, such as economic disruption to the Port of Seattle and fisheries mitigation

EPA guidance, according to CERCLA requirements, notes that the amount and quality of remedial investigation data needed to develop and scope remedial alternatives correspond to an expected accuracy for FS cost estimates of approximately –30 to +50% (EPA 2000). Costs provided within this appendix are intended to fall within this range of accuracy.

5 REFERENCES

AECOM, 2012. Feasibility Study, Lower Duwamish Waterway, Seattle, Washington. Final Report. Prepared for Lower Duwamish Waterway Group. October 2012.

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TABLES

Table 1
Unit Costs

Item No.	Item Description	Unit Cost (2016)	Unit	Unit Cost Notes
Pre-construction				
1	**Mobilization/Demobilization**			
1a	Mobilization/Demobilization	$ 700,000	Annual	Includes mobilization and demobilization of removal and placement operations, barges, equipment preparation, ancillary equipment, and procedural costs. Equivalent to approximately 20 days of mobilization and 15 days of demobilization (assuming daily costs of 75% of the daily costs during dredging [Table 3]).
1b	Initial Transload Site Setup	$ 1,000,000	Project	Costs would be variable depending on the transload site selected and the design approach. Costs could include land lease or land purchase, permitting, transload crane, temporary containment vault, water treatment system, amendment delivery system, container loading area (truck or rail), and rail spur or container transload area.
1c	Annual Transload Site Setup and Maintenance (After Initial)	$ 500,000	Annual	Costs would be variable depending on the transload site selected and the design approach. Costs could include land lease, permit renewals, equipment setup and maintenance (crane, vault, water treatment, amendment delivery, and truck and rail routes), and demobilization (decontamination and deconstruction).
1d	Mobilization/Demobilization for Underpier Dredging Equipment	$ 250,000	Annual	Includes hydraulic dredge, water treatment facility, and diving equipment. Applied to each year that underpier dredging occurs.
1e	Mobilization/Demobilization for Equipment to Dredge under the West Seattle Bridge	$ 500,000	Annual	Includes mobilization and demobilization of limited access equipment from the uplands, development of a truck loading area under the West Seattle Bridge, and a cost to shutdown the bridge and reroute traffic. Applied to each year that dredging under the West Seattle Bridge occurs.
2	**Pre-construction Activities**			
2a	Pre-construction activities	$ 100,000	Annual	Preparation of staging areas, stockpile areas, implementation of site controls, preparation of pre-construction submittals. Applied to each construction season.
Construction				
3	**Removal, Dewatering, Offloading, and Disposal**			
3a	Open-water Dredging	$ 27	cy	Based on the production rate and daily costs presented in Table 3. The cost per cubic yard includes all equipment and labor necessary for dredging and dewatering.
3b	Restricted Access Dredging (Under West Seattle Bridge)	$ 119	cy	Based on the production rate and daily costs presented in Table 3. The cost per cubic yard includes all equipment and labor necessary for dredging and dewatering. Costs account for limited equipment access, limited space for maneuvering equipment, and cost for trucking to rail (as opposed to barge transportation).
3c	Diver-Assisted Hydraulic Dredging (Underpier)	$ 600	cy	Based on the production rate and daily costs presented in Table 3 developed from contractor input and best professional judgement. EW project conditions including deep water, limited access, and presence of rip rap. This item presents a high uncertainty (recent Anchor QEA project experience shows costs could be as high as $1,100/cy). The cost per cubic yard includes all equipment and labor necessary for dredging. Water treatment is not included.
3d	Water Treatment (Underpier Hydraulic Dredging)	$ 400	cy	Cost based on discussions with contractors involved with water treatment on the LDW, with consideration of specific needs for the EW (barge mounted treatment system and additional barges for surge capacity). With the estimated hydraulic dredging fraction of 10% sediment, 90% water by volume, the unit cost equals $0.22/gallon of water.
3e	Transload, Transportation and Disposal	$ 70	Ton	Cost includes material transfer from barge onto offloading area, water management at transloading facility, load dewatered sediment onto truck with containers, truck transport to rail facility, rail transport to the Subtitle D landfill, offloading of sediments from railcars at Subtitle D landfill. Assume 1.5 ton/cy. Costs based on recent project experience. Costs do not include mobilization, permitting and construction of the transload facility.

Table 1
Unit Costs

Item No.	Item Description	Unit Cost (2016)	Unit	Unit Cost Notes
4	**Pile Removal and Disposal**	$ 1,000	Each	Includes removal and disposal. Based on recent project experience.
5	**Engineered Capping and Residuals Management Cover**			
5a	Furnish Sand	$ 20	cy	Based on recent project experience, cost estimates and CalPortland pricing. Applies to Engineered Cap Isolation Layer, Backfill, RMC, and ENR in open-water areas. Material costs are based on the purchase from local or regional quarries. Unit costs include the cost and transportation of the material.
5b	Furnish Gravel	$ 20	cy	Based on recent project experience, cost estimates and CalPortland pricing. Applies to Engineered Cap Filter Layer. Material costs are based on the purchase from local or regional quarries. Unit costs include the cost and transportation of the material.
5c	Furnish Armor Material	$ 35	cy	Based on recent project experience, cost estimates and CalPortland pricing. Applies to Engineered Cap Armor Layer. Material costs are based on the purchase from local or regional quarries. Unit costs include the cost and transportation of the material.
5d	Furnish In situ Treatment Material (AquaGate+PAC^{TM})	$ 500	cy	Consistent with recent pilot study at the Puget Sound Naval Shipyard in Bremerton, WA. This pilot study was completed using the AquaGate+PAC^{TM} composite aggregate system. Transportation was not factored into the unit cost to account for an assumed cost reduction for a full-scale application.
5e	Place Sand - Unrestricted Access	$ 26	cy	Based on the production rate and daily costs presented in Table 3. The cost per cubic yard includes all equipment and labor necessary for placement and material handling.
5f	Place Gravel - Unrestricted Access	$ 26	cy	Based on the production rate and daily costs presented in Table 3. The cost per cubic yard includes all equipment and labor necessary for placement and material handling.
5g	Place Armor Material - Unrestricted Access	$ 43	cy	Based on the production rate and daily costs presented in Table 3. The cost per cubic yard includes all equipment and labor necessary for placement and material handling.
5h	Place in situ Material in Difficult to Access Areas - Underpier	$ 400	cy	Based on production rate consistent with recent pilot study at the Puget Sound Naval Shipyard in Bremerton, WA. This pilot study was completed using the AquaGate+PAC^{TM} composite aggregate system. See Table 3.
5i	Place ENR Material in Difficult to Access Areas - Low Bridge	$ 400	cy	Based on production rate consistent with recent pilot study at the Puget Sound Naval Shipyard in Bremerton, WA. See Table 3.
6	**Surveys and Monitoring**			
6a	**Payment Surveys**	$ 40,000	Site-wide Event	East Waterway Group project experience. Assume one event before and after each construction season.
6b	Contractor daily progress surveys	$ 2,500	Day	Based on recent project experience and cost estimates.
7	**Sales Tax and Contingency**			
7a	Sales Tax	9.5%	--	Percent of subtotal of pre-construction costs and construction base costs.
7b	Contingency	30%	--	Percent of construction costs. Typical Conceptual-level Contingency; mid-range of EPA FS Cost Guidance for contingency. Percent of pre-construction, construction, and tax.

Table 1
Unit Costs

Item No.	Item Description	Unit Cost (2016)	Unit	Unit Cost Notes
Indirect Construction Costs				
8	**Pre-construction**			
8a	Design and Permitting	5%	--	Percent of construction costs. Typical Conceptual-level Contingency; mid-range of EPA FS Cost Guidance for contingency. Percent of pre-construction, construction, and tax. Includes sampling during remedial design.
8b	Pre-Construction Base-line Monitoring	Alternative-specific	Lump Sum	See Table 4 and Appendix E.
8c	Project Management (Owners)	1%	--	Percent of construction costs.
8d	Agency Review and Oversight	$ 500,000	Annual	Assume 3 years for pre-construction activities.
9	**During Construction**			
9a	Construction Management Support	10%	--	Percent of construction costs. Typical Conceptual-level Contingency; mid-range of EPA FS Cost Guidance for contingency. Percent of pre-construction, construction, and tax.
9b	**Environmental Compliance**			
9bi	Water Quality Monitoring	$ 3,000	Day	Includes labor, equipment, materials, and analytical testing. Analytical cost: assume four monitoring stations approx. 30% of field screening samples required for chemical analysis.
9bii	Confirmational Sampling	Alternative-specific	Lump Sum	See Table 4 and Appendix E.
9c	Project Management (Owners)	4%	--	Percent of construction costs.
9d	Agency Review and Oversight	$ 500,000	Annual	Annually during construction.
10	**Post-construction Costs**			
10a	Operations and Maintenance and Long Term Monitoring 1 through 20 years post-construction	Alternative-specific	Lump Sum	See Table 4 and Appendix E.
10b	Contingency Remediation (Adaptive Management) - Open Water	$ 1,100,000	Acre	Capitol cost for dredging open water without contingencies, design, project management, etc. Assume adaptive management required over 15% of ENR areas. Based on an average neatline dredge depth of 3.5 feet and the unit costs for dredging and disposal.
10c	Contingency Remediation (Adaptive Management) - Underpier and Low Bridge	$ 4,100,000	Acre	Approximate capitol cost for dredging under piers without contingencies, design, project management, etc. Assume adaptive management required over 15% of MNR, ENR, and in situ treatment areas. Based on an average dredge depth of 2.3 feet and the unit costs for dredging, water management and disposal.
10d	Project Management (Owners)	1%	--	Percent of construction costs.
10e	Agency Review and Oversight	$ 120,000	Annual	Assume 25 years for post-construction activities. Equivalent to $200,000/yr during 5-year reviews and $100,000/yr between 5-year reviews.

Table 2
Unit Cost Assumptions for Dredging and Material Placement

Parameter	Unit	Open-water Dredging	Restricted Access Dredging (West Seattle Bridge)	Diver-Assisted Underpier Hydraulic Dredging	Sand and Gravel Placement	Armor Placement	Underpier Placement
Unit Cost Calculation							
Production Rate	cy/day	1,100	270	40	940	560	60
Daily Cost	/day	$30,000	$24,000	$24,000	$24,000	$24,000	$24,000
Additional Trucking Cost (to Rail Facility)	/cy	$0	$30	$0	$0	$0	$0
Cost per Unit Dredge Volume	**/cy**	**$27**	**$119**	**$600**	**$26**	**$43**	**$400**
Production Rate Calculation							
Cycle Time	min	2.50	3.00	n/a	1.50	2.50	n/a
Bucket Capacity	cy	8	4	n/a	4	4	n/a
Effective Bucket Capacity	%	70%	70%	n/a	70%	70%	n/a
Effective Bucket Capacity	cy	5.6	2.8	n/a	2.8	2.8	n/a
Shift Duration	hrs	12	12	n/a	12	12	n/a
Work Day	shift/day	1	1	n/a	1	1	n/a
Efficiency	%	70%	40%	n/a	70%	70%	n/a
Daily Production	cy	1,129	269	n/a	941	564	n/a
Daily Production (rounded)	**cy**	**1,100**	**270**	**40**	**940**	**560**	**60**
Daily Rate Calculation							
Daily Cost - Equipment							
Dredge or Telebelt	/day	$9,000	$6,500	$10,000	$6,500	$6,500	$6,500
Tug	/day	$5,000	$5,000	n/a	$5,000	$5,000	$5,000
Barge(s)	/day	$5,000	$2,500	n/a	$2,500	$2,500	$2,500
Work Boat	/day	$1,500	$1,500	n/a	$1,500	$1,500	$1,500
Front-end loader	/day	$800	$800	n/a	$800	$800	$800
Diving Equipment and Boats	/day	n/a	n/a	$3,500	n/a	n/a	n/a
Total - Equipment	/day	$21,300	$16,300	$13,500	$16,300	$16,300	$16,300
Fuel, Oil and Grease (FOB; 20%)	/day	$4,260	$3,260	$2,700	$3,260	$3,260	$3,260
Total - Equipment + FOB	**/day**	**$25,560**	**$19,560**	**$16,200**	**$19,560**	**$19,560**	**$19,560**
Daily Cost - Labor							
Superintendent	/day	$700	$700	$700	$700	$700	$700
Operator Foreman	/day	$680	$680	n/a	$680	$680	$680
Dredge Operator	/day	$600	$600	n/a	$600	$600	$600
Deck Hands - Dredge	/day	$1,200	$1,200	n/a	$1,200	$1,200	$1,200
Tug Operator	/day	$600	$600	n/a	$600	$600	$600
Deck Hand - Tug	/day	$600	$600	n/a	$600	$600	$600
Divers and Diver Support (6 Crew Members)	/day	n/a	n/a	$6,600	n/a	n/a	n/a
Total - Labor	**/day**	**$4,380**	**$4,380**	**$7,300**	**$4,380**	**$4,380**	**$4,380**
Grand Total Labor + Equipment	**/day**	**$29,940**	**$23,940**	**$23,500**	**$23,940**	**$23,940**	**$23,940**
Grand Total Labor + Equipment (rounded)	**/day**	**$30,000**	**$24,000**	**$24,000**	**$24,000**	**$24,000**	**$24,000**

Notes:
1. Unit cost assumptions based on engineering cost estimate methodology and bids on recent projects.
cy - cubic yard
hrs - hours
min - minute
n/a - not applicable

Table 3
Monitoring Costs

Unit Cost Estimates

Alternative	SAP and Data Report (All Analyses)	Surface Sediment	Porewater	Cores	Tissue	Surface Water	Bathymetric Survey and Physical Inspections
Analytical, data validation, data management	n/a	$1,778	$2,375	$7,112	$1,601	$380	n/a
Samples/day	n/a	10	4	6	4	4	n/a
Mob/ demob/ equipment/ reporting	$100,000	$7,500	$30,500	$2,000	$1,000	$0	$40,000
Sampling cost/day	n/a	$3,300	$3,300	$3,750	$3,300	$3,300	n/a

Note:
1. Unit cost estimates developed from recent Anchor QEA project experience.

Total Quantities and Costs by Event

Alternative	Sample Quantity							Cost				
										Sampling		
	SAP and Data Report (All Analyses)	Surface Sediment	Porewater	Cores	Tissue	Surface Water	Bathymetric Survey and Physical Inspections	Analytical, Data Validation, and Data Management Costs	Mobilization, Demobilization, Equipment, and Reporting Costs	Sampling Days	Sampling Cost	Total Cost
Pre-construction Baseline Sampling												
No Action	0	0	0	0	0	0	0	$0	$0	0	$0	$0
1A(12)	1	62	0	0	20	8	1	$145,280	$148,500	13	$43,560	$337,340
1B(12)	1	62	13	13	20	8	1	$268,606	$181,000	19	$62,410	$512,016
1C+(12)	1	62	13	13	20	8	1	$268,606	$181,000	19	$62,410	$512,016
2A(12)	1	58	0	0	20	8	1	$138,168	$148,500	13	$42,240	$328,908
2B(12)	1	58	13	13	20	8	1	$261,494	$181,000	18	$61,090	$503,584
2C(12)	1	57	11	11	20	8	1	$240,743	$181,000	17	$57,860	$479,603
2C+(12)	1	58	13	13	20	8	1	$261,494	$181,000	18	$61,090	$503,584
3B(12)	1	56	13	13	20	8	1	$257,938	$181,000	18	$60,430	$499,368
3C+(12)	1	56	13	13	20	8	1	$257,938	$181,000	18	$60,430	$499,368
3D(12)	1	50	0	0	20	8	1	$123,945	$148,500	12	$39,600	$312,045
2C+(7.5)	1	56	13	13	20	8	1	$257,938	$181,000	18	$60,430	$499,368
3C+(7.5)	1	54	13	13	20	8	1	$254,382	$181,000	18	$59,770	$495,152
3E(7.5)	1	54	13	13	20	8	1	$254,382	$181,000	18	$59,770	$495,152
2C+(5.0)	1	58	14	14	20	8	1	$270,981	$181,000	19	$62,540	$514,521
3D(5.0)	1	49	0	0	20	8	1	$122,167	$148,500	12	$39,270	$309,937
3E(5.0)	1	56	14	14	20	8	1	$267,425	$181,000	18	$61,880	$510,305

Table 3
Monitoring Costs

Alternative	Sample Quantity							Cost				
	SAP and Data Report (All Analyses)	Surface Sediment	Porewater	Cores	Tissue	Surface Water	Bathymetric Survey and Physical Inspections	Analytical, Data Validation, and Data Management Costs	Mobilization, Demobilization, Equipment, and Reporting Costs	Sampling: Sampling Days	Sampling: Sampling Cost	Total Cost
Confirmational Sampling												
No Action	0	0	0	0	0	0	0	$0	$0	0	$0	$0
1A(12)	1	62	0	0	0	8	1	$113,266	$147,500	8	$27,060	$287,826
1B(12)	1	62	13	13	0	8	1	$236,592	$180,000	14	$45,910	$462,502
1C+(12)	1	62	13	13	0	8	1	$236,592	$180,000	14	$45,910	$462,502
2A(12)	1	58	0	0	0	8	1	$106,154	$147,500	8	$25,740	$279,394
2B(12)	1	58	13	13	0	8	1	$229,480	$180,000	13	$44,590	$454,070
2C(12)	1	57	11	11	0	8	1	$208,729	$180,000	12	$41,360	$430,089
2C+(12)	1	58	13	13	0	8	1	$229,480	$180,000	13	$44,590	$454,070
3B(12)	1	56	13	13	0	8	1	$225,924	$180,000	13	$43,930	$449,854
3C+(12)	1	56	13	13	0	8	1	$225,924	$180,000	13	$43,930	$449,854
3D(12)	1	50	0	0	0	8	1	$91,931	$147,500	7	$23,100	$262,531
2C+(7.5)	1	56	13	13	0	8	1	$225,924	$180,000	13	$43,930	$449,854
3C+(7.5)	1	54	13	13	0	8	1	$222,368	$180,000	13	$43,270	$445,638
3E(7.5)	1	55	13	13	0	8	1	$224,146	$180,000	13	$43,600	$447,746
2C+(5.0)	1	58	14	14	0	8	1	$238,967	$180,000	14	$46,040	$465,007
3D(5.0)	1	49	0	0	0	8	1	$90,153	$147,500	7	$22,770	$260,423
3E(5.0)	1	56	14	14	0	8	1	$235,411	$180,000	13	$45,380	$460,791
Operations and Maintenance Monitoring and Long-term Monitoring												
Year 1												
No Action	1	39	0	0	0	0	0	$69,338	$107,500	4	$12,870	$189,708
1A(12)	1	62	0	0	20	8	1	$145,280	$148,500	13	$43,560	$337,340
1B(12)	1	62	13	13	20	8	1	$268,606	$181,000	19	$62,410	$512,016
1C+(12)	1	62	13	13	20	8	1	$268,606	$181,000	19	$62,410	$512,016
2A(12)	1	58	0	0	20	8	1	$138,168	$148,500	13	$42,240	$328,908
2B(12)	1	58	13	13	20	8	1	$261,494	$181,000	18	$61,090	$503,584
2C(12)	1	57	11	11	20	8	1	$240,743	$181,000	17	$57,860	$479,603
2C+(12)	1	58	13	13	20	8	1	$261,494	$181,000	18	$61,090	$503,584
3B(12)	1	56	13	13	20	8	1	$257,938	$181,000	18	$60,430	$499,368
3C+(12)	1	56	13	13	20	8	1	$257,938	$181,000	18	$60,430	$499,368
3D(12)	1	50	0	0	20	8	1	$123,945	$148,500	12	$39,600	$312,045
2C+(7.5)	1	56	13	13	20	8	1	$257,938	$181,000	18	$60,430	$499,368
3C+(7.5)	1	54	13	13	20	8	1	$254,382	$181,000	18	$59,770	$495,152
3E(7.5)	1	55	13	13	20	8	1	$256,160	$181,000	18	$60,100	$497,260
2C+(5.0)	1	58	14	14	20	8	1	$270,981	$181,000	19	$62,540	$514,521
3D(5.0)	1	49	0	0	20	8	1	$122,167	$148,500	12	$39,270	$309,937
3E(5.0)	1	56	14	14	20	8	1	$267,425	$181,000	18	$61,880	$510,305

Table 3
Monitoring Costs

Alternative	Sample Quantity							Cost				
	SAP and Data Report (All Analyses)	Surface Sediment	Porewater	Cores	Tissue	Surface Water	Bathymetric Survey and Physical Inspections	Analytical, Data Validation, and Data Management Costs	Mobilization, Demobilization, Equipment, and Reporting Costs	Sampling: Sampling Days	Sampling: Sampling Cost	Total Cost
Year 3												
No Action	0	0	0	0	0	0	0	$0	$0	0	$0	$0
1A(12)	1	31	0	0	20	0	0	$87,129	$108,500	8	$26,730	$222,359
1B(12)	1	31	13	13	20	0	0	$210,455	$141,000	14	$45,580	$397,035
1C+(12)	1	31	13	13	20	0	0	$210,455	$141,000	14	$45,580	$397,035
2A(12)	1	23	0	0	20	0	0	$72,906	$108,500	7	$24,090	$205,496
2B(12)	1	23	13	13	20	0	0	$196,232	$141,000	13	$42,940	$380,172
2C(12)	1	21	11	11	20	0	0	$173,703	$141,000	12	$39,380	$354,083
2C+(12)	1	23	13	13	20	0	0	$196,232	$141,000	13	$42,940	$380,172
3B(12)	1	19	13	13	20	0	0	$189,120	$141,000	12	$41,620	$371,740
3C+(12)	1	19	13	13	20	0	0	$189,120	$141,000	12	$41,620	$371,740
3D(12)	1	6	0	0	20	0	0	$42,681	$108,500	6	$18,480	$169,661
2C+(7.5)	1	23	13	13	20	0	0	$196,232	$141,000	13	$42,940	$380,172
3C+(7.5)	1	19	13	13	20	0	0	$189,120	$141,000	12	$41,620	$371,740
3E(7.5)	1	20	13	13	20	0	0	$190,898	$141,000	12	$41,950	$373,848
2C+(5.0)	1	24	14	14	20	0	0	$207,496	$141,000	13	$44,720	$393,216
3D(5.0)	1	6	0	0	20	0	0	$42,681	$108,500	6	$18,480	$169,661
3E(5.0)	1	20	14	14	20	0	0	$200,384	$141,000	13	$43,400	$384,784
Years 5, 10, 15, and 20												
No Action	1	39	0	0	0	0	0	$69,338	$107,500	4	$12,870	$189,708
1A(12)	1	62	0	0	20	8	1	$145,280	$148,500	13	$43,560	$337,340
1B(12)	1	62	13	13	20	8	1	$268,606	$181,000	19	$62,410	$512,016
1C+(12)	1	62	13	13	20	8	1	$268,606	$181,000	19	$62,410	$512,016
2A(12)	1	58	0	0	20	8	1	$138,168	$148,500	13	$42,240	$328,908
2B(12)	1	58	13	13	20	8	1	$261,494	$181,000	18	$61,090	$503,584
2C(12)	1	57	11	11	20	8	1	$240,743	$181,000	17	$57,860	$479,603
2C+(12)	1	58	13	13	20	8	1	$261,494	$181,000	18	$61,090	$503,584
3B(12)	1	56	13	13	20	8	1	$257,938	$181,000	18	$60,430	$499,368
3C+(12)	1	56	13	13	20	8	1	$257,938	$181,000	18	$60,430	$499,368
3D(12)	1	50	0	0	20	8	1	$123,945	$148,500	12	$39,600	$312,045
2C+(7.5)	1	56	13	13	20	8	1	$257,938	$181,000	18	$60,430	$499,368
3C+(7.5)	1	54	13	13	20	8	1	$254,382	$181,000	18	$59,770	$495,152
3E(7.5)	1	54	13	13	20	8	1	$254,382	$181,000	18	$59,770	$495,152
2C+(5.0)	1	58	14	14	20	8	1	$270,981	$181,000	19	$62,540	$514,521
3D(5.0)	1	49	0	0	20	8	1	$122,167	$148,500	12	$39,270	$309,937
3E(5.0)	1	56	14	14	20	8	1	$267,425	$181,000	18	$61,880	$510,305

Notes:
1. Monitoring sample quantities are developed in FS Appendix G.
2. Approximate sampling numbers and costs are for FS purposes only.
FS - Feasibility Study
n/a - not applicable
SAP - sampling and analysis plan

Table 4
Estimated Construction Durations

	Unit			Alternative																
Construction Description	**Assumption**	**Notes**	**Unit**	**No Action**	**1A(12)**	**1B(12)**	**1C+(12)**	**2A(12)**	**2B(12)**	**2C(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**3D(12)**	**2C+(7.5)**	**3C+(7.5)**	**3E(7.5)**	**2C+(5.0)**	**3D(5.0)**	**3E(5.0)**
Dredging																				
Open-water Dredging	1,100 cy/day	Based on dredge production calculations	cy	0	813,120	813,120	813,120	902,212	902,212	902,212	902,212	938,455	938,455	938,455	1,007,892	1,016,453	1,016,453	1,077,140	1,086,121	1,086,121
			days	0	739	739	739	820	820	820	820	853	853	853	916	924	924	979	987	987
Limited Access Dredging (Under West Seattle Bridge)	270 cy/day	Based on dredge production calculations	cy	0	0	0	0	0	0	0	0	16,651	16,651	16,651	0	19,365	19,365	0	19,737	19,737
			days	0	0	0	0	0	0	0	0	62	62	62	0	72	72	0	73	73
Hydraulic Dredging (Underpier)	40 cy/day	Vendor quote and best professional judgment	cy	0	0	0	7,016	0	0	7,016	7,016	0	7,016	43,940	7,016	7,016	46,216	7,016	48,816	48,816
			days	0	0	0	175	0	0	175	175	0	175	1,098	175	175	1,155	175	1,220	1,220
Total Dredging Time		**Assumed concurrent operations**	**days**	**0**	**739**	**739**	**739**	**820**	**820**	**820**	**820**	**853**	**853**	**1,098**	**916**	**924**	**1,155**	**979**	**1,220**	**1,220**
Placement - Capping, Backfill, ENR, and In situ Treatment																				
Placement - Sand or Gravel	940 cy/day	Based on recent Puget Sound project experience	cy	0	166,191	166,796	166,730	137,278	137,883	137,821	137,821	129,695	129,372	128,282	134,884	127,571	125,986	127,790	119,003	119,003
			days	0	177	177	177	146	147	147	147	138	138	136	143	136	134	136	127	127
Placement - Armor	560 cy/day	Based on recent Puget Sound project experience	cy	0	30,931	30,931	30,931	30,931	30,931	30,931	30,931	17,654	17,654	17,654	31,062	17,786	17,786	31,062	17,786	17,786
			days	0	55	55	55	55	55	55	55	32	32	32	55	32	32	55	32	32
Placement - Underpier or Under Low Bridge	60 cy/day	Underpier in situ or ENR under low bridges; based on recent pilot study	cy	0	811	5,678	5,678	1,421	6,288	5,506	6,288	6,288	6,288	1,421	6,675	6,675	6,675	6,963	1,562	6,963
			days	0	14	95	95	24	105	92	105	105	105	24	111	111	111	116	26	116
Total Placement Time		**Assumed concurrent operations in open-water and underpier**	**days**	**0**	**232**	**233**	**233**	**201**	**202**	**202**	**202**	**169**	**169**	**168**	**199**	**167**	**166**	**191**	**158**	**158**
Placement - Dredge Residuals Management Cover																				
Placement - Sand	940 cy/day	Based on recent Puget Sound project experience	cy	0	88,580	88,580	88,580	106,341	106,341	106,341	106,341	111,735	111,735	111,735	118,258	123,607	123,592	127,233	132,566	132,566
			days	0	94	94	94	113	113	113	113	119	119	119	126	131	131	135	141	141
Total Construction Time (Best Estimate)																				
Total construction time assuming some concurrent dredging and placement operations	**100 days/ season**	**Total of dredging and residuals management operations during the anticipated construction window (October 1 through February 15)**	**days**	**0**	**833**	**833**	**833**	**933**	**933**	**933**	**933**	**972**	**972**	**1,217**	**1,042**	**1,056**	**1,287**	**1,115**	**1,361**	**1,361**
			seasons	**0**	**8.3**	**8.3**	**8.3**	**9.3**	**9.3**	**9.3**	**9.3**	**9.7**	**9.7**	**12.2**	**10.4**	**10.6**	**12.9**	**11.1**	**13.6**	**13.6**
Total Construction Time (With Extended Construction Season)																				
Total construction time assuming some concurrent dredging and placement operations	**150 days/ season**	**Assume production during an extended construction window (July 16 to September 30) with 50% production during that time due to tribal fishing.**	**days**	**0**	**833**	**833**	**833**	**933**	**933**	**933**	**933**	**972**	**972**	**1,217**	**1,042**	**1,056**	**1,287**	**1,115**	**1,361**	**1,361**
			seasons	**0**	**6.7**	**6.7**	**6.7**	**7.5**	**7.5**	**7.5**	**7.5**	**7.8**	**7.8**	**9.7**	**8.3**	**8.4**	**10.3**	**8.9**	**10.9**	**10.9**

Notes:
1. See Table 3 for construction rate assumption.
cy - cubic yards
ENR - enhanced natural recovery

Table 5
Quantities and Costs for Alternatives

Item No.	Item Description	Unit Cost	Unit	Quantity by Alternative																
				No Action	1A(12)	1B(12)	1C+(12)	2A(12)	2B(12)	2C(12)	2C+(12)	3B(12)	3C+(12)	3D(12)	2C+(7.5)	3C+(7.5)	3E(7.5)	2C+(5.0)	3D(5.0)	3E(5.0)
Pre-construction																				
1	**Mobilization/Demobilization**																			
1a	Mobilization/Demobilization	$ 700,000	Annual	0	9	9	9	10	10	10	10	10	10	13	11	11	13	12	14	14
1b	Initial Transload Site Setup	$ 1,000,000	Project	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1c	Annual Transload Site Setup and Maintenance (After Initial)	$ 500,000	Annual	0	8	8	8	9	9	9	9	9	9	12	10	10	12	11	13	13
1d	Mobilization/Demobilization for Underpier Dredging Equipment	$ 250,000	Annual	0	0	0	2	0	0	2	2	0	2	11	2	2	12	2	13	13
1e	Mobilization/Demobilization for Equipment to Dredge under the West Seattle Bridge	$ 500,000	Annual	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	1	1
2	**Pre-construction activities**																			
2a	Pre-construction activities	$ 100,000	Annual	0	9	9	9	10	10	10	10	10	10	13	11	11	13	12	14	14
	Subtotal Pre-construction			n/a																
Construction																				
3	**Removal, Dewatering, Offloading, and Disposal**																			
3a	Open-water Dredging	$ 27	cy	0	813,120	813,120	813,120	902,212	902,212	902,212	902,212	938,455	938,455	938,455	1,007,892	1,016,453	1,016,453	1,077,140	1,086,121	1,086,121
3b	Restricted Access Dredging (Under West Seattle Bridge)	$ 119	cy	0	0	0	0	0	0	0	0	16,651	16,651	16,651	0	19,365	19,365	0	19,737	19,737
3c	Diver-Assisted Hydraulic Dredging (Underpier)	$ 600	cy	0	0	0	7,016	0	0	7,016	7,016	0	7,016	43,940	7,016	7,016	46,216	7,016	48,816	48,816
3d	Water Treatment (Underpier Hydraulic Dredging)	$ 400	cy	0	0	0	7,016	0	0	7,016	7,016	0	7,016	43,940	7,016	7,016	46,216	7,016	48,816	48,816
3e	Transload, Transportation and Disposal	$ 70	Ton	0	1,219,680	1,219,680	1,230,203	1,353,319	1,353,319	1,363,842	1,363,842	1,432,659	1,443,182	1,498,569	1,522,362	1,564,250	1,623,050	1,626,233	1,732,012	1,732,012
4	**Pile Removal and Disposal**	$ 1,000	Each	0	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
5	**Engineered Capping and Residuals Management Cover**																			
5a	Furnish Sand	$ 20	cy	0	234,961	235,566	235,500	224,420	225,025	224,962	224,962	231,082	230,759	229,669	233,995	240,883	239,282	235,876	241,274	241,274
5b	Furnish Gravel	$ 20	cy	0	20,620	20,620	20,620	20,620	20,620	20,620	20,620	11,769	11,769	11,769	20,708	11,857	11,857	20,708	11,857	11,857
5c	Furnish Armor Material	$ 35	cy	0	30,931	30,931	30,931	30,931	30,931	30,931	30,931	17,654	17,654	17,654	31,062	17,786	17,786	31,062	17,786	17,786
5d	Furnish In situ Treatment Material (AquaGate+PAC^{TM})	$ 500	cy	0	0	4,867	4,867	0	4,867	4,085	4,867	4,867	4,867	0	5,113	5,113	5,113	5,401	0	5,401
5e	Place Sand - Unrestricted Access	$ 26	cy	0	234,151	234,756	234,690	222,999	223,604	223,541	223,541	229,661	229,338	228,247	232,434	239,322	237,720	234,315	239,712	239,712
5f	Place Gravel - Unrestricted Access	$ 26	cy	0	20,620	20,620	20,620	20,620	20,620	20,620	20,620	11,769	11,769	11,769	20,708	11,857	11,857	20,708	11,857	11,857
5g	Place Armor Material - Unrestricted Access	$ 43	cy	0	30,931	30,931	30,931	30,931	30,931	30,931	30,931	17,654	17,654	17,654	31,062	17,786	17,786	31,062	17,786	17,786
5h	Place in situ Material in Difficult to Access Areas - Underpier	$ 400	cy	0	0	4,867	4,867	0	4,867	4,085	4,867	4,867	4,867	0	5,113	5,113	5,113	5,401	0	5,401
5i	Place ENR Material in Difficult to Access Areas - Low Bridge	$ 400	cy	0	811	811	811	1,421	1,421	1,421	1,421	1,421	1,421	1,421	1,562	1,562	1,562	1,562	1,562	1,562
6	**Surveys and Monitoring**																			
6a	**Payment Surveys**	$ 40,000	Site-wide Event	0	17	17	17	19	19	19	19	20	20	25	21	22	26	23	28	28
6b	Contractor daily progress surveys	$ 2,500	Day	0	833	833	833	933	933	933	933	972	972	1,217	1,042	1,056	1,287	1,115	1,361	1,361
	Subtotal Construction Base Costs			n/a																
7	**Sales Tax and Contingency**																			
7a	Sales Tax	9.5%	--	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7b	Contingency	30%	--	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Subtotal Construction Costs			n/a																

Table 5
Quantities and Costs for Alternatives

Item No.	Item Description	Unit Cost	Unit	Quantity by Alternative																
				No Action	1A(12)	1B(12)	1C+(12)	2A(12)	2B(12)	2C(12)	2C+(12)	3B(12)	3C+(12)	3D(12)	2C+(7.5)	3C+(7.5)	3E(7.5)	2C+(5.0)	3D(5.0)	3E(5.0)
Indirect Construction Costs																				
8	**Pre-construction**																			
8a	Design and Permitting	5%	--	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8b	Pre-Construction Base-line Monitoring	Alternative-specific	Lump Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8c	Project Management (Owners)	1%	--	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8d	Agency Review and Oversight	$500,000	Annual	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
9	**During Construction**																			
9a	Construction Management Support	10%	--	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9b	**Environmental Compliance**																			
9bi	Water Quality Monitoring	$ 3,000	Day	0	833	833	833	933	933	933	933	972	972	1,217	1,042	1,056	1,287	1,115	1,361	1,361
9bii	Confirmational Sampling	Alternative-specific	Lump Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9c	Project Management (Owners)	4%	--	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9d	Agency Review and Oversight	$ 500,000	Annual	0	9	9	9	10	10	10	10	10	10	13	11	11	13	12	14	14
10	**Post-construction Costs**																			
10a	Operations and Maintenance and Long Term Monitoring 1 through 20 years post-construction	Alternative-specific	Lump Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10b	Contingency Remediation (Adaptive Management) - Open Water	$1,100,000	Acre	0	2.6	2.7	2.7	0.2	0.3	0.3	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0
10c	Contingency Remediation (Adaptive Management) - Underpier and Low Bridge	$4,100,000	Acre	0	2.1	2.0	1.7	2.1	2.0	1.7	1.7	2.0	1.7	0.2	1.8	1.8	0.2	1.9	0.2	0.2
10d	Project Management (Owners)	1%	--	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10e	Agency Review and Oversight	$120,000	Annual	0	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Subtotal Indirect Construction Costs			**n/a**																
	Total Cost			**n/a**																
	Total Cost (rounded)			**n/a**																

Table 5
Quantities and Costs for Alternatives

		Cost by Alternative																
Item No.	**Item Description**	**No Action**	**1A(12)**	**1B(12)**	**1C+(12)**	**2A(12)**	**2B(12)**	**2C(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**3D(12)**	**2C+(7.5)**	**3C+(7.5)**	**3E(7.5)**	**2C+(5.0)**	**3D(5.0)**	**3E(5.0)**
Pre-construction																		
1	**Mobilization/Demobilization**																	
1a	Mobilization/Demobilization	$ -	$ 6,300,000	$ 6,300,000	$ 6,300,000	$ 7,000,000	$ 7,000,000	$ 7,000,000	$ 7,000,000	$ 7,000,000	$ 7,000,000	$ 9,100,000	$ 7,700,000	$ 7,700,000	$ 9,100,000	$ 8,400,000	$ 9,800,000	$ 9,800,000
1b	Initial Transload Site Setup	$ -	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000
1c	Annual Transload Site Setup and Maintenance (After Initial)	$ -	$ 4,000,000	$ 4,000,000	$ 4,000,000	$ 4,500,000	$ 4,500,000	$ 4,500,000	$ 4,500,000	$ 4,500,000	$ 4,500,000	$ 6,000,000	$ 5,000,000	$ 5,000,000	$ 6,000,000	$ 5,500,000	$ 6,500,000	$ 6,500,000
1d	Mobilization/Demobilization for Underpier Dredging Equipment	$ -	$ -	$ -	$ 500,000	$ -	$ -	$ 500,000	$ 500,000	$ -	$ 500,000	$ 2,750,000	$ 500,000	$ 500,000	$ 3,000,000	$ 500,000	$ 3,250,000	$ 3,250,000
1e	Mobilization/Demobilization for Equipment to Dredge under the West Seattle Bridge	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 500,000	$ 500,000	$ 500,000	$ -	$ 500,000	$ 500,000	$ -	$ 500,000	$ 500,000
2	**Pre-construction activities**																	
2a	Pre-construction activities	$ -	$ 900,000	$ 900,000	$ 900,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,300,000	$ 1,100,000	$ 1,100,000	$ 1,300,000	$ 1,200,000	$ 1,400,000	$ 1,400,000
	Subtotal Pre-construction	**$ -**	**$ 12,200,000**	**$ 12,200,000**	**$ 12,700,000**	**$ 13,500,000**	**$ 13,500,000**	**$ 14,000,000**	**$ 14,000,000**	**$ 14,000,000**	**$ 14,500,000**	**$ 20,650,000**	**$ 15,300,000**	**$ 15,800,000**	**$ 20,900,000**	**$ 16,600,000**	**$ 22,450,000**	**$ 22,450,000**
Construction																		
3	**Removal, Dewatering, Offloading, and Disposal**																	
3a	Open-water Dredging	$ -	$ 22,175,996	$ 22,175,996	$ 22,175,996	$ 24,605,792	$ 24,605,792	$ 24,605,792	$ 24,605,792	$ 25,594,218	$ 25,594,218	$ 25,594,218	$ 27,487,971	$ 27,721,452	$ 27,721,452	$ 29,376,535	$ 29,621,487	$ 29,621,487
3b	Restricted Access Dredging (Under West Seattle Bridge)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,979,634	$ 1,979,634	$ 1,979,634	$ -	$ 2,302,259	$ 2,302,259	$ -	$ 2,346,533	$ 2,346,533
3c	Diver-Assisted Hydraulic Dredging (Underpier)	$ -	$ -	$ -	$ 4,209,372	$ -	$ -	$ 4,209,372	$ 4,209,372	$ -	$ 4,209,372	$ 26,363,963	$ 4,209,372	$ 4,209,372	$ 27,729,303	$ 4,209,372	$ 29,289,875	$ 29,289,875
3d	Water Treatment (Underpier Hydraulic Dredging)	$ -	$ -	$ -	$ 2,806,248	$ -	$ -	$ 2,806,248	$ 2,806,248	$ -	$ 2,806,248	$ 17,575,976	$ 2,806,248	$ 2,806,248	$ 18,486,202	$ 2,806,248	$ 19,526,583	$ 19,526,583
3e	Transload, Transportation and Disposal	$ -	$ 85,377,585	$ 85,377,585	$ 86,114,225	$ 94,732,297	$ 94,732,297	$ 95,468,938	$ 95,468,938	$ 100,286,107	$ 101,022,747	$ 104,899,801	$ 106,565,327	$ 109,497,535	$ 113,613,523	$ 113,836,299	$ 121,240,859	$ 121,240,859
4	**Pile Removal and Disposal**	$ -	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000
5	**Engineered Capping and Residuals Management Cover**																	
5a	Furnish Sand	$ -	$ 4,699,224	$ 4,711,327	$ 4,710,006	$ 4,488,400	$ 4,500,502	$ 4,499,248	$ 4,499,248	$ 4,621,645	$ 4,615,184	$ 4,593,375	$ 4,679,908	$ 4,817,666	$ 4,785,631	$ 4,717,530	$ 4,825,470	$ 4,825,470
5b	Furnish Gravel	$ -	$ 412,407	$ 412,407	$ 412,407	$ 412,407	$ 412,407	$ 412,407	$ 412,407	$ 235,387	$ 235,387	$ 235,387	$ 414,163	$ 237,144	$ 237,145	$ 414,163	$ 237,144	$ 237,144
5c	Furnish Armor Material	$ -	$ 1,082,570	$ 1,082,570	$ 1,082,570	$ 1,082,570	$ 1,082,570	$ 1,082,570	$ 1,082,570	$ 617,891	$ 617,891	$ 617,891	$ 1,087,177	$ 622,502	$ 622,507	$ 1,087,177	$ 622,502	$ 622,502
5d	Furnish In situ Treatment Material (AquaGate+PAC™)	$ -	$ -	$ 2,433,435	$ 2,433,436	$ -	$ 2,433,435	$ 2,042,296	$ 2,433,436	$ 2,433,435	$ 2,433,436	$ -	$ 2,556,650	$ 2,556,650	$ 2,556,669	$ 2,700,692	$ -	$ 2,700,692
5e	Place Sand - Unrestricted Access	$ -	$ 5,978,311	$ 5,993,761	$ 5,992,074	$ 5,693,581	$ 5,709,031	$ 5,707,430	$ 5,707,430	$ 5,863,681	$ 5,855,433	$ 5,827,592	$ 5,934,480	$ 6,110,341	$ 6,069,445	$ 5,982,507	$ 6,120,304	$ 6,120,304
5f	Place Gravel - Unrestricted Access	$ -	$ 526,478	$ 526,478	$ 526,478	$ 526,478	$ 526,478	$ 526,478	$ 526,478	$ 300,494	$ 300,494	$ 300,494	$ 528,718	$ 302,737	$ 302,739	$ 528,718	$ 302,737	$ 302,737
5g	Place Armor Material - Unrestricted Access	$ -	$ 1,325,595	$ 1,325,595	$ 1,325,595	$ 1,325,595	$ 1,325,595	$ 1,325,595	$ 1,325,595	$ 756,602	$ 756,602	$ 756,602	$ 1,331,237	$ 762,247	$ 762,253	$ 1,331,237	$ 762,247	$ 762,247
5h	Place in situ Material in Difficult to Access Areas - Underpier	$ -	$ -	$ 1,946,748	$ 1,946,749	$ -	$ 1,946,748	$ 1,633,837	$ 1,946,749	$ 1,946,748	$ 1,946,749	$ -	$ 2,045,320	$ 2,045,320	$ 2,045,335	$ 2,160,554	$ -	$ 2,160,554
5i	Place ENR Material in Difficult to Access Areas - Low Bridge	$ -	$ 324,280	$ 324,280	$ 324,280	$ 568,559	$ 568,559	$ 568,559	$ 568,559	$ 568,559	$ 568,559	$ 568,559	$ 624,644	$ 624,644	$ 624,644	$ 624,644	$ 624,644	$ 624,644
6	**Surveys and Monitoring**																	
6a	**Payment Surveys**	$ -	$ 680,000	$ 680,000	$ 680,000	$ 760,000	$ 760,000	$ 760,000	$ 760,000	$ 800,000	$ 800,000	$ 1,000,000	$ 840,000	$ 880,000	$ 1,040,000	$ 920,000	$ 1,120,000	$ 1,120,000
6b	Contractor daily progress surveys	$ -	$ 2,083,584	$ 2,083,584	$ 2,083,584	$ 2,333,304	$ 2,333,304	$ 2,333,304	$ 2,333,304	$ 2,430,019	$ 2,430,019	$ 3,043,414	$ 2,605,179	$ 2,638,864	$ 3,217,170	$ 2,786,429	$ 3,403,597	$ 3,403,597
	Subtotal Construction Base Costs	*$ -*	*$ 125,666,030*	*$ 130,073,766*	*$ 137,823,021*	*$ 137,528,983*	*$ 141,936,719*	*$ 148,982,073*	*$ 149,686,125*	*$ 149,434,421*	*$ 157,171,974*	*$ 194,356,905*	*$ 164,716,394*	*$ 169,134,982*	*$ 213,116,278*	*$ 174,482,105*	*$ 221,043,982*	*$ 225,905,228*
7	**Sales Tax and Contingency**																	
7a	Sales Tax	$ -	$ 13,097,273	$ 13,516,008	$ 14,299,687	$ 14,347,753	$ 14,766,488	$ 15,483,297	$ 15,550,182	$ 15,526,270	$ 16,308,838	$ 20,425,656	$ 17,101,557	$ 17,568,823	$ 22,231,546	$ 18,152,800	$ 23,131,928	$ 23,593,747
7b	Contingency	$ -	$ 45,288,991	$ 46,736,932	$ 49,446,812	$ 49,613,021	$ 51,060,962	$ 53,539,611	$ 53,770,892	$ 53,688,207	$ 56,394,243	$ 70,629,768	$ 59,135,386	$ 60,751,142	$ 76,874,347	$ 62,770,471	$ 79,987,773	$ 81,584,692
	Subtotal Construction Costs	**$ -**	**$ 196,252,294**	**$ 202,526,706**	**$ 214,269,521**	**$ 214,989,757**	**$ 221,264,170**	**$ 232,004,981**	**$ 233,007,199**	**$ 232,648,899**	**$ 244,375,055**	**$ 306,062,330**	**$ 256,253,337**	**$ 263,254,947**	**$ 333,122,172**	**$ 272,005,376**	**$ 346,613,683**	**$ 353,533,667**

Table 5
Quantities and Costs for Alternatives

Item No.	Item Description	Cost by Alternative																
		No Action	1A(12)	1B(12)	1C+(12)	2A(12)	2B(12)	2C(12)	2C+(12)	3B(12)	3C+(12)	3D(12)	2C+(7.5)	3C+(7.5)	3E(7.5)	2C+(5.0)	3D(5.0)	3E(5.0)
Indirect Construction Costs																		
8	**Pre-construction**																	
8a	Design and Permitting	$ -	$ 9,812,615	$ 10,126,335	$ 10,713,476	$ 10,749,488	$ 11,063,208	$ 11,600,249	$ 11,650,360	$ 11,632,445	$ 12,218,753	$ 15,303,116	$ 12,812,667	$ 13,162,747	$ 16,656,109	$ 13,600,269	$ 17,330,684	$ 17,676,683
8b	Pre-Construction Base-line Monitoring	$ -	$ 337,340	$ 512,016	$ 512,016	$ 328,908	$ 503,584	$ 479,603	$ 503,584	$ 499,368	$ 499,368	$ 312,045	$ 499,368	$ 495,152	$ 495,152	$ 514,521	$ 309,937	$ 510,305
8c	Project Management (Owners)	$ -	$ 1,962,523	$ 2,025,267	$ 2,142,695	$ 2,149,898	$ 2,212,642	$ 2,320,050	$ 2,330,072	$ 2,326,489	$ 2,443,751	$ 3,060,623	$ 2,562,533	$ 2,632,549	$ 3,331,222	$ 2,720,054	$ 3,466,137	$ 3,535,337
8d	Agency Review and Oversight	$ -	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000
9	**During Construction**																	
9a	Construction Management Support	$ -	$ 12,566,603	$ 13,007,377	$ 13,782,302	$ 13,752,898	$ 14,193,672	$ 14,898,207	$ 14,968,613	$ 14,943,442	$ 15,717,197	$ 19,435,691	$ 16,471,639	$ 16,913,498	$ 21,311,628	$ 17,448,210	$ 22,104,398	$ 22,590,523
9b	**Environmental Compliance**																	
9bi	Water Quality Monitoring	$ -	$ 2,500,301	$ 2,500,301	$ 2,500,301	$ 2,799,965	$ 2,799,965	$ 2,799,965	$ 2,799,965	$ 2,916,023	$ 2,916,023	$ 3,652,097	$ 3,126,215	$ 3,166,637	$ 3,860,604	$ 3,343,715	$ 4,084,316	$ 4,084,316
9bii	Confirmational Sampling	$ -	$ 287,826	$ 462,502	$ 462,502	$ 279,394	$ 454,070	$ 430,089	$ 454,070	$ 449,854	$ 449,854	$ 262,531	$ 449,854	$ 445,638	$ 447,746	$ 465,007	$ 260,423	$ 460,791
9c	Project Management (Owners)	$ -	$ 7,850,092	$ 8,101,068	$ 8,570,781	$ 8,599,590	$ 8,850,567	$ 9,280,199	$ 9,320,288	$ 9,305,956	$ 9,775,002	$ 12,242,493	$ 10,250,133	$ 10,530,198	$ 13,324,887	$ 10,880,215	$ 13,864,547	$ 14,141,347
9d	Agency Review and Oversight	$ -	$ 4,500,000	$ 4,500,000	$ 4,500,000	$ 5,000,000	$ 5,000,000	$ 5,000,000	$ 5,000,000	$ 5,000,000	$ 5,000,000	$ 6,500,000	$ 5,500,000	$ 5,500,000	$ 6,500,000	$ 6,000,000	$ 7,000,000	$ 7,000,000
10	**Post-construction Costs**																	
10a	Operations and Maintenance and Long Term Monitoring 1 through 20 years post-construction	$ 948,541	$ 1,909,058	$ 2,957,113	$ 2,957,113	$ 1,850,037	$ 2,898,092	$ 2,752,097	$ 2,898,092	$ 2,868,581	$ 2,868,581	$ 1,729,886	$ 2,877,013	$ 2,847,502	$ 2,851,718	$ 2,965,819	$ 1,719,347	$ 2,936,308
10b	Contingency Remediation (Adaptive Management) - Open Water	$ -	$ 2,862,169	$ 2,944,686	$ 2,944,686	$ 197,878	$ 280,395	$ 280,395	$ 280,395	$ -	$ -	$ -	$ 313,544	$ -	$ -	$ 313,544	$ -	$ -
10c	Contingency Remediation (Adaptive Management) - Underpier and Low Bridge	$ -	$ 8,450,982	$ 8,143,418	$ 6,950,606	$ 8,450,982	$ 8,143,418	$ 6,950,606	$ 6,950,606	$ 8,143,418	$ 6,950,606	$ 722,446	$ 7,397,631	$ 7,397,631	$ 793,710	$ 7,836,900	$ 793,710	$ 793,710
10d	Project Management (Owners)	$ -	$ 1,962,523	$ 2,025,267	$ 2,142,695	$ 2,149,898	$ 2,212,642	$ 2,320,050	$ 2,330,072	$ 2,326,489	$ 2,443,751	$ 3,060,623	$ 2,562,533	$ 2,632,549	$ 3,331,222	$ 2,720,054	$ 3,466,137	$ 3,535,337
10e	Agency Review and Oversight	$ -	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000	$ 3,000,000
	Subtotal Indirect Construction Costs	**$ 948,541**	**$ 59,502,030**	**$ 61,805,349**	**$ 62,679,172**	**$ 60,808,935**	**$ 63,112,254**	**$ 63,611,510**	**$ 63,986,116**	**$ 64,912,066**	**$ 65,782,886**	**$ 70,781,552**	**$ 69,323,132**	**$ 70,224,103**	**$ 77,403,998**	**$ 73,308,307**	**$ 78,899,637**	**$ 81,764,657**
	Total Cost	**$ 948,541**	**$ 255,754,324**	**$ 264,332,055**	**$ 276,948,693**	**$ 275,798,693**	**$ 284,376,424**	**$ 295,616,491**	**$ 296,993,315**	**$ 297,560,965**	**$ 310,157,941**	**$ 376,843,882**	**$ 325,576,469**	**$ 333,479,050**	**$ 410,526,170**	**$ 345,313,684**	**$ 425,513,320**	**$ 435,298,324**
	Total Cost (rounded)	**$ 950,000**	**$ 256,000,000**	**$ 264,000,000**	**$ 277,000,000**	**$ 276,000,000**	**$ 284,000,000**	**$ 296,000,000**	**$ 297,000,000**	**$ 298,000,000**	**$ 310,000,000**	**$ 377,000,000**	**$ 326,000,000**	**$ 333,000,000**	**$ 411,000,000**	**$ 345,000,000**	**$ 426,000,000**	**$ 435,000,000**

Table 6
Alternatives Cost Summary

Item	Alternative																
	No Action	**1A(12)**	**1B(12)**	**1C+(12)**	**2A(12)**	**2B(12)**	**2C(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**3D(12)**	**2C+(7.5)**	**3C+(7.5)**	**3E(7.5)**	**2C+(5.0)**	**3D(5.0)**	**3E(5.0)**
Total Cost	$ 948,541	$ 255,754,324	$ 264,332,055	$ 276,948,693	$ 275,798,693	$ 284,376,424	$ 295,616,491	$ 296,993,315	$ 297,560,965	$ 310,157,941	$ 376,843,882	$ 325,576,469	$ 333,479,050	$ 410,526,170	$ 345,313,684	$ 425,513,320	$ 435,298,324
Total Cost (rounded)	$ 950,000	$ 256,000,000	$ 264,000,000	$ 277,000,000	$ 276,000,000	$ 284,000,000	$ 296,000,000	$ 297,000,000	$ 298,000,000	$ 310,000,000	$ 377,000,000	$ 326,000,000	$ 333,000,000	$ 411,000,000	$ 345,000,000	$ 426,000,000	$ 435,000,000

APPENDIX F – VOLUME CALCULATIONS
EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

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1 INTRODUCTION

A key component of developing and evaluating remedial alternatives for the East Waterway (EW) Operable Unit (OU) Feasibility Study (FS) is estimating the volume of contaminated sediment that would potentially be removed as part of remediation, and the amount of material placed in the waterway as part of capping, enhanced natural recovery (ENR), residuals management, or in situ treatment. In particular, the sediment volumes for removal and disposal are a major driver of estimated costs and construction timeframes for all of the remedial alternatives.

This appendix summarizes the methods used to estimate removal and placement volumes in the FS, and discusses the following:

1. The methods used to create a triangular irregular network (TIN) surface and subsequently develop isopach layers of contaminated sediment removal thickness (Section 2.1) to determine neatline volumes for the Deep Main Body Reach, Shallow Main Body Reach, and adjacent berthing areas.
2. Determining sediment neatline volume estimates for other Construction Management Areas (CMAs). All other CMAs were completed using various methods, which typically consisted of multiplying the surface area and a sediment thickness (Section 2.2).
3. Determining the sediment neatline volume estimates for partial dredging and capping and partial dredging and ENR in the navigation channel or berthing areas (ENR-nav) (Section 2.3).
4. Determining the estimated total removal volume for the alternatives (Section 2.4).
5. Methods for estimating placement volumes (Section 3).
6. Uncertainties in the data and methods (Section 4).

The level of accuracy of the estimated volumes in this FS is considered sufficient for calculating dredged material removal volumes for remedial alternatives. Volume estimates will require refinement during the remedial design phase prior to remedial action.

2 METHODS FOR CALCULATING VOLUME OF CONTAMINATED SEDIMENT

The FS has divided the EW into CMAs, grouping areas with similar characteristics and common remedial technology assignments. The following sections describe the methods for estimating neatline volumes in each CMA. Neatline volumes are the volumes of contaminated sediment determined by multiplying removal depth by area prior to considering slopes, overdredge, and other constructability factors.

2.1 Development of the Triangular Irregular Network and Neatline Dredge Volumes

The thickness of contaminated sediment in the Deep and Shallow Main Body Reaches and adjacent berthing areas (T-18 Berth Area, T-25 Berth Area, and T-30 Berth Area) was estimated by identifying the deepest depth of contaminated sediment for each core and interpolating between core locations with a TIN for the three sets[1] of remedial action levels (RALs) developed in FS Section 6. A TIN creates an interpolated surface by drawing straight-line slopes between depths of sediment exceeding RALs determined from sediment cores. All of the cores in the Supplemental Remedial Investigation (SRI)/FS dataset were used to create the TIN surfaces, with the exception of cores that have been dredged subsequent to sampling. For duplicate samples, the average of the two concentrations was used to determine neatline dredging depths.

The depth of contamination for each core was determined by reviewing the detected RAL exceedances (see Section 6 of the FS) of all core sample intervals for each set of RALs. Note that, although RALs were not developed for all benthic risk-drivers, the depth of contamination determined by all RAL exceedances resulted in the inclusion of all detected exceedances of all benthic risk drivers where the removal technology is used. In other words, dredging to the base of RAL exceedances will also remove the full set of benthic risk-driver exceedances at each core location, because all benthic risk-driver exceedances are co-located with RAL exceedances in the FS dataset. To compensate for any core compaction during sampling, the core interval depths were divided by the percent recovery for each core, where this information was available. If percent recovery was not available, the sample

[1] Differences in RAL sets are for PCBs only; all other COCs have the same RAL. The three PCB RALs are 12, 7.5, and 5 mg/kg OC.

interval depths were used without applying a compaction correction. Four types of results were obtained from the cores and the depth of contamination was determined, as follows:

- If the deepest RAL exceedance was just above an interval without a detected RAL exceedance, then the depth of contaminated sediment was assumed to be at the contact between the two intervals.
- If the deepest RAL exceedance was just above an interval that was not analyzed, then the un-analyzed interval was assumed to be a RAL exceedance, and the depth of contamination was assumed to be the top of the next interval without a detected RAL exceedance.
- If the deepest sample interval was a RAL exceedance, then the depth of contamination was assumed to be the depth of the core plus an additional 1 foot. This was a reasonable assumption based on comparing these core locations to nearby cores where the depth of contamination was bounded.
- If the core had no RAL exceedances, then the depth of contamination was assumed to be 1 foot if the core was within the remediation footprint (i.e., if the surface sediment at that core location exceeds RALs), and 0 feet if the core was outside the remediation area (i.e., if surface sediment at that core location does not exceed RALs).

The depths of contamination for each core, as determined by the metrics described above, were inputted into a CAD program to generate a TIN surface based on thickness below the existing sediment surface (i.e., the TIN was generated as a thickness of contaminated sediment as opposed to an elevation; Figures 1a, 1b, 2a, 2b, 3a, and 3b). Manual points were entered into the TIN surface to simulate a contamination thickness of 2 feet at the pier faces and at the edge of the site in locations without piers. This assumption represents a reasonable estimate of the average thickness of sediment at the pier faces based on jet probe data under the piers (see Section 2.2.2 for discussion of jet probe data under the piers), and represents a reasonable boundary condition for areas without pier structures. Note that in practice, the full thickness of contaminated sediment along pier faces may not be able to be removed without compromising structures or slopes; the FS assumes that dredging in areas adjacent to piers and slopes would occur to the maximum extent practicable and remaining contamination would be addressed as part of residuals management.

The dredging neatline volume was determined in CAD by multiplying TIN thicknesses by removal area for each TIN, as presented in Tables 1a and 1b. The neatline volume calculation assumes vertical cuts from mudline down to the dredging elevation along the boundary of dredging areas (e.g., bordering unremediated areas). During construction, these locations would be sloped for sediment stability, as discussed in Section 2.4.

2.2 Development of Remaining Construction Management Area Dredging Neatline Volumes

For the remaining CMAs, the TIN was not used because TIN-layer boundary assumptions have a larger influence on the dredging volume and do not accurately represent the proposed removal actions in the alternatives. In particular, small CMAs with a large proportion of shoreline and few sediment cores would have dredging depths determined by TIN boundary assumptions, as opposed to actual data. Therefore, volumes were calculated for each area individually by the methods described in the following sections.

2.2.1 Open-water Construction Management Areas

Dredging volumes for the smaller open-water CMAs, including the Sill Reach, Former Pier 24 Piling Field, T-25 Nearshore, Mound Area and Slip 27 Shoreline, Slip 27 Channel, T-30 Nearshore, T-46 Offshore, and Slip 36, were based on an average removal thickness for each RAL set obtained from core data in each area. Note that the dredge depth was the same for all three RAL sets for all cores in these areas. For these CMAs, the contamination thicknesses of the applicable cores were averaged to estimate contamination thickness across the CMA. This thickness was then multiplied by the surface area of the CMA to derive neatline volumes, as shown in Tables 1a and 1b.

2.2.2 Underpier Construction Management Area

The volume of all sediment (both above RALs and below RALs) in the underpier CMA was estimated by analyzing jet probe data and cross sections. For T-18, T-25, and T-30 under piers, jet probe data collected by Sunchasers in 1998 and 2000 were used to measure the lateral extent of sediment in underpier areas and sediment thickness along transects (Sunchasers 2000). Estimations were made of the cross sectional areas of soft sediment at representative bents. The cross sectional areas of soft sediment based on the jet probe data were multiplied by the representative pier length to estimate the total volume of soft sediment. For Slip 27 and T-46 under piers, jet probe data were not available, so cross sections that approximated original construction conditions (Anchor and Windward 2008) were used to estimate sediment cross sectional areas based on multibeam bathymetry collected in underpier areas. From these cross sections, the area of sediment was calculated based on the depiction of soft sediment on the drawing, or by inferring a 2.5 horizontal to 1 vertical (2.5H:1V) sediment slope starting approximately halfway down the riprap slope to the edge of the pier face. The cross sectional area was multiplied by the length of the structures to estimate a total volume. Finally, for Pier 36/37, because of the lack of information regarding underpier conditions, 2.0 feet of sediment was estimated over half of the footprint under the Pier 36/37 structure to calculate volumes.

For all underpier areas, the total volume of sediment estimated was approximately 51,000 cubic yards (cy). The volume of contaminated sediment requiring removal was then assumed to be proportional to the area of underpier sediment requiring removal relative to the total area of underpier sediment (14.4 acres). For Underpier Options C and C+, the removal area was 1.9 acres, resulting in a volume of 7,016 cy. For Underpier Options D and E, the removal area was 12.1 acres, 12.7 acres, and 13.4 acres for the RAL sets, which included 12 milligrams per kilogram of organic carbon (mg/kg OC), 7.5 mg/kg OC, and 5.0 mg/kg OC for PCBs, respectively. The resulting removal volumes were 43,940 cy, 46,216 cy, and 48,816 cy, respectively.

2.2.3 Communication Cable Crossing

A communication cable is positioned within a rock structure that crosses the EW between stations 1400 to 2000 located at elevations from approximately -70 feet MLLW up to -50 feet MLLW, depending on the location in the waterway. Moving, replacing, or modifying the communications cable crossing would be a challenging and expensive modification to infrastructure in the EW. Due to uncertainties with existing conditions in the Communication Cable Crossing CMA and lack of as-built or cable survey information, an estimated sediment thickness of 3 feet to the top of the cable's armored trench was used to determine the volume of removal in this CMA. Neatline volume was calculated by multiplying removal depth by dredging area. Additional investigations will be required during design to determine the sediment thickness over the ballast rock to more accurately characterize conditions to perform the maximum practicable removal of contaminated sediment in the location.

2.3 Partial Dredging Depth Volume Calculations

2.3.1 Partial Dredging and Capping

Partial dredging and capping is part of all remedial alternatives for two or more CMAs. The assumptions used to calculate partial dredging volumes were different for the Shallow Main Body Reach and nearshore areas and are described in more detail in this section.

Partial dredging and capping was assigned in the Shallow Main Body Reach for Open-water Technology Groups 1 and 2 (see Appendix L or Section 8). In these areas, the partial dredging depth depended on maintaining the required operational navigation elevations. In the Shallow Main Body – North (Stations 4950 to 6200), the operational depth required to maintain site use is -40 feet mean lower low water (MLLW). To accommodate an assumed 4-foot buffer, the top of the cap would be at -44 feet MLLW. This requires a partial dredging elevation of -49 feet MLLW to allow for an assumed 5-foot-thick cap (see Section 7.2.5.1 of the FS). In the Shallow Main Body – South (Stations 6200 to 6800), the operational depth required to maintain site use is -30 feet MLLW. Subsequently, the top of the cap would be at -34 feet MLLW. This requires a partial dredging elevation at -39 feet MLLW to accommodate a 5-foot-thick cap. The partial dredging depth was calculated as the existing bathymetric sediment surface elevation minus the partial dredging elevation requirements described above. In certain areas of these CMAs, the existing sediment surface elevation is at or below the partial dredging elevation, and no dredging would be necessary to place a cap in these areas (only capping would be necessary). Where the partial dredging depth is greater than the thickness of contamination, the thickness of contamination was considered the partial dredging depth and constitutes the volumes provided for the Shallow Main Body Reach in Table 1b. The dredging isopach needed to accommodate partial dredging and capping is presented in Figures 4a and 4b. The dredging depth depicted in Figures 4a and 4b was multiplied by area to estimate the neatline dredging volume in these areas.

In the Mound Area/Slip 27 Shoreline, Slip 27 Head, and the Coast Guard Nearshore, the partial dredging depth was assumed to be 5 feet for the FS, to accommodate a 5-foot cap while restoring the surface elevations to the existing grade. In some areas, additional removal would be necessary to ensure that the surface of the final cap is at a stable grade once appropriate offsets from the navigation channel are included. In particular, the Mound Area would require significant additional removal in the area adjacent to the navigation channel to create stable slopes (e.g., 3V:1H) from the edge of the navigation channel. To accommodate this slope, an additional removal of approximately 7,800 cy of material would be required, and is included in the volume estimate.

2.3.2 Partial Dredging and ENR-nav

Partial dredging and ENR-nav is part of Open-water Technology Group 1 in the Deep Main Body Reach, Communication Cable Crossing area, and Deep Draft Berthing Areas. In these areas, the partial dredging depth was calculated to fit an assumed 1.5-foot-thick ENR-nav layer. Partial dredging was assumed to extend to -54 feet MLLW, approximately 3 feet below the maintenance dredging depths. Where the partial dredging depth is greater than the thickness of contamination, the thickness of contamination was considered the partial dredging depth. The dredging isopach needed to accommodate partial dredging and ENR-nav is presented in Figures 4a and 4b. The dredging depth depicted in Figure 2 was multiplied by area to estimate the neatline dredging volume in these areas.

2.4 Constructable Dredge Volume Calculation

Neatline volumes including those previously described under-represent the amount of material that will be removed during construction due to several factors, including the following:

- Additional volume required to design constructable dredge prisms, consisting of flat-bottom or constant thickness units with stable side slopes. Additional volume is also generated with dredge prisms from side slopes between dredge units and adjacent unremediated areas, and payable overdepth allowances.
- Additional horizontal and vertical sediment volumes (e.g., presence of contaminants below the currently estimated depth of contamination), particularly where cores had RAL exceedances in the deepest interval.

- Additional volume for sedimentation that may occur before remedy implementation.
- An allowance to account for slumping sediment within the dredge prism.

To account for the multiple allowances listed above, the neatline volumes were increased by 50% to represent the anticipated construction dredge volume. This adjustment is consistent with the method used in the LDW (e.g., AECOM 2012), and is derived from actual removal volumes for large sediment remediation sites (Palermo 2009). A constructability factor of 1.5 was multiplied by the neatline dredging volumes in all CMAs except the Underpier CMA. In these areas, dredging would be performed down to the underlying rock slope (i.e., down to the riprap layer); therefore, several of the increased volume allowances above do not apply, and the volume factor was not applied in these areas.

Placing the constructability factor into context shows that the neatline volume times 1.5 is reasonable for the EW, based on project experience in the EW. The average neatline dredge depth is about 3.5 feet for the alternatives. Because a typical overdredging depth is 1 foot beyond the targeted construction depth, overdredging contributes about 30% of the constructability volume. Therefore, the other 20% of the constructability volume (an average of 8 inches over the entire dredging area) is from the other factors, including dredge prism design, side slopes, sloughing, and additional characterization. The 8 inches of allowance for these factors is reasonable based on project experience.

2.5 Total Volume Estimates for Remedial Alternatives

Table 2 provides the total rounded dredging volumes for the remedial alternatives. The total volumes range from 810,000 cy (Alternative 1A(12)) to 1,150,000 cy (Alternative 3E(5.0)).

3 PLACEMENT VOLUME CALCULATION

Table 3 provides the placement volume calculation by CMA. The placement volumes are calculated based on placement thickness multiplied by area. The placement volume assumptions for the FS are listed in the following bullets; material specifications and thicknesses will be revisited during remedial design, and suitable habitat substrates will be used where applicable. These placement depths are developed in FS Section 7.2.5.1, based on the analysis in Appendix D (for capping).

- Capping is assumed to be 5 feet thick and consist of the following:
  - 1.5 feet of armor (stone)
  - 1 foot of filter material (gravel)
  - 2.5 feet of isolation material (sand with controlled total organic carbon (TOC) or activated carbon (AC) as necessary as determined in design)
- ENR and residuals management cover are assumed to be 9 inches thick (sand)
- In situ treatment is assumed to be 3 inches thick (AC plus substrate)
- Backfill thickness is assumed to be the same as the removal thickness in the area requiring backfill (sand)

The total placement volumes for the CMAs and alternatives are shown on Tables 3 and 4.

4 SOURCES OF UNCERTAINTY

The removal volume estimates represent the estimate of future dredge volumes based on current information. The following list provides a summary of the major uncertainties associated with this estimate:

- The accuracy of the volume estimate is limited by the density of core data, and the dredging volume will change with additional sediment characterization.
  - Although the EW OU is well characterized, approximately 63 of 146 cores used in the volume analysis (43%) had exceedances at the base of the core. Most of these locations were cores that were sampled for dredge material disposal characterization and were sectioned in 4 feet or greater increments. In these locations in particular, deeper contamination than the assumed 1 additional foot could be encountered during remedial design (Section 2.1). Based on the average dredge depth in Table 2, if an additional 1 foot of contaminated sediment were present below the base of these cores (for a total of 2 feet of contaminated sediment below the base of these cores), then the total project dredging volume (and associated costs) would increase by about 12%. For the alternatives, this uncertainty is assumed to be captured by the constructability factor of 1.5 times the neatline volume, and by contingency costs (which are 30% of total capital costs).
  - Cores with thicker sample intervals (e.g., 4 feet) have greater uncertainty in estimating the depth of contaminated sediment exceeding RALs (i.e., neatline dredge depth). The neatline dredge depth could be thicker or thinner than estimated depending on the effect of compositing layers of higher concentrations with layers of lower concentrations (i.e., an exceedance could be masked by blending or drawn deeper by blending).
  - Approximately 36 acres of the EW OU is outside of the remediation footprint because sediments are below RALs. The boundaries of remediation areas may need to be adjusted based on remedial design sampling.
- The dredging volume will be adjusted to account for structural and slope limitations during design.

- As discussed in the FS, structural stability will limit dredging adjacent to structures and slopes. During construction, some contaminated sediment will remain in place and will be managed as part of residuals management and, subsequently, will not be incorporated into the total removal volume.
- Typical maximum stable dredge-cut slopes are approximately 3H:1V; however, the TIN surface was generated with no slope restrictions and, therefore, likely underestimates the final volume relative to when slopes are incorporated into the design.

In general, these key uncertainties are accounted for by the 1.5 constructability factor, as described in Section 2.4.

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TABLES

Table 1a
Remediation Areas, Technology Assignments, and Average Dredge Depth by Construction Management Area

CMA	Total Area (Acres)	Remediation Area For RAL Set[a] (acres): RAL Set including 12 mg/kg OC for PCBs	RAL Set including 7.5 mg/kg OC for PCBs	RAL Set including 5.0 mg/kg OC for PCBs[b]	Technology Option[c]: Open-water Option 1	Open-water Option 2	Open-water Option 3	Average Dredge Depth (feet)[d]: Open-water Option 1, RAL Set including 12 mg/kg OC	Open-water Option 2, RAL Set including 12 mg/kg OC	Open-water Option 3, RAL Set including 12 mg/kg OC	Open-water Option 2, RAL Set including 7.5 mg/kg OC	Open-water Option 3, RAL Set including 7.5 mg/kg OC	Open-water Option 2, RAL Set including 5.0 mg/kg OC	Open-water Option 3, RAL Set including 5.0 mg/kg OC
Open-water CMAs														
Deep Main Body – North and South	56.4	43.0	47.3	50.2	Removal/ Partial Removal and ENR-nav	Removal	Removal	2.7	3.5	3.5	3.4	3.4	3.4	3.4
T-18 Berth Area	18.7	15.2	16.7	17.3	Removal/ Partial Removal and ENR-nav	Removal	Removal	2.2	2.3	2.3	2.2	2.2	2.3	2.3
T-25 Berth Area	5.7	4.8	4.8	5.3	Removal	Removal	Removal	3.7	3.7	3.7	3.8	3.8	3.8	3.8
T-30 Berth Area	6.6	4.7	5.6	5.6	Removal	Removal	Removal	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Slip 36	7.1	5.0	6.5	7.1	Removal	Removal	Removal	2.3	2.3	2.3	2.4	2.4	2.5	2.5
Slip 27 Channel	2.4	2.4	2.4	2.4	Removal	Removal	Removal	7.2	7.2	7.2	7.4	7.4	7.6	7.6
T-25 Nearshore	0.5	0.5	0.5	0.5	Removal	Removal	Removal	5.0	5.0	5.0	5.2	5.2	5.3	5.3
T-30 Nearshore	3.2	3.1	3.1	3.1	Removal	Removal	Removal	4.3	4.3	4.3	4.4	4.4	4.5	4.5
T-46 Offshore	2.0	0.0	0.4	0.4	n/a	Removal	Removal	n/a	n/a	n/a	5.0	5.0	5.1	5.1
Shallow Main Body – North	14.0	9.5	9.5	11.6	Removal/ Partial Removal and Cap	Removal/ Partial Removal and Cap	Removal	3.7	3.7	4.4	4.5	4.5	4.7	4.7
Shallow Main Body – South	6.6	4.5	5.3	6.1	Removal/ Partial Removal and Cap	Removal/ Partial Removal and Cap	Removal	3.8	3.8	5.0	4.6	4.6	4.6	4.6
Sill Reach – West Seattle Bridge	1.9	1.7	1.9	1.9	ENR-sill	ENR-sill	Removal	n/a	n/a	4.1	n/a	4.2	n/a	4.3
Sill Reach – Low Bridges	1.8	1.2	1.3	1.3	ENR-sill/ MNR	ENR-sill	ENR-sill	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Junction Reach	2.2	0.0	0.5	0.5	n/a	Removal	Removal	n/a	n/a	n/a	3.6	3.6	3.7	3.7
Former Pier 24 Piling Field	1.1	1.1	1.1	1.1	Partial Removal and Cap	Partial Removal and Cap	Removal	5.0	5.0	7.9	5.0	8.2	5.0	8.4
Mound Area and Slip 27	5.0	5.0	5.0	5.0	Partial Removal and Cap	Partial Removal and Cap	Partial Removal and Cap	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Coast Guard Nearshore	2.5	2.5	2.5	2.5	Partial Removal and Cap	Partial Removal and Cap	Partial Removal and Cap	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Communication Cable Crossing	5.1	4.8	4.8	4.8	Removal/ Partial Removal and ENR-nav	Removal	Removal	2.1	3.0	3.0	3.0	3.0	3.0	3.0
Subtotal	**143**	**109**	**119**	**127**										

CMA	Total Area (Acres)	RAL Set including 12 mg/kg OC for PCBs	RAL Set including 7.5 mg/kg OC for PCBs	RAL Set #3 (5 mg/kg OC)	CSL for PCBs and Hg	Underpier Options A & B	Underpier Options C & C+	Underpier Option D	Underpier Options E	Underpier Options A & B	Underpier Options C & C+ & D & E (Same Removal Depth for all Options)[e]
Underpier CMA											
Underpier	14.4	12.1	12.7	13.4	1.9	No removal (MNR & In Situ Treatment Respectively)	Diver assisted hydraulic dredging in areas exceeding CSL for PCBs and Hg (also in situ treatment)	Diver assisted hydraulic dredging in areas exceeding RALs	Diver assisted hydraulic dredging in areas exceeding RALs (also in situ treatment)	n/a	2.3

Total Remediation Area	**157**	**121**	**132**	**140**

Notes:
a. The RALs are presented in FS Section 6. The RAL sets for the alternatives are distinguished based on the PCB RALs: 12 mg/kg OC (121 acres of remediation), 7.5 mg/kg OC (131 acres of remediation), and 5.0 mg/kg OC (144 acres of remediation).
b. The RAL of 5.0 mg/kg OC was not carried forward in the detailed evaluation of alternatives (FS Section 9), as described in FS Appendix L.
c. Open-water technology options 1, 2, and 3 denote the following: 1 = Removal with capping and ENR where applicable; 2 = Removal with capping where applicable; and 3 = Maximum removal to the extent practicable. Underpier technology options A, B, C, D and E denote the following: A = MNR; B = In situ treatment; C = Diver-assisted hydraulic dredging in areas exceeding CSL for PCBs and Hg and in situ treatment for other areas exceeding RALs; C+ = Same as C, but with in situ treatment employed within the diver-assisted dredging areas following removal; D = Diver-assisted hydraulic dredging; and E = Diver-assisted hydraulic dredging followed by in situ treatment.
d. For neatline volumes calculated using dredge depths, the average dredge depths are the average depths to base of contamination of the cores listed in Table 1b.
e. The dredging depth in the underpier is based on cross sectional area down to riprap, and is therefore the same for all underpier technology options and RAL sets.

CAD - computer-aided drafting
CMA - Construction Management Area
ENR-nav - enhanced natural recovery applied in the navigation channel and deep-draft berthing areas
ENR-sill - enhanced natural recovery used in the Sill Reach
MNR - monitored natural recovery
n/a - not applicable (no removal)
OC - organic-carbon normalized
RAL - remedial action level
TIN - triangular irregular network

Table 1b
Neatline and Total Dredge Volumes by Construction Management Area

CMA	Neatline Dredge Volume (cy) [a]							Method for Calculating Neatline Volume	Constructability Factor[b]	Total Dredge Volume by Alternative (PCB RAL in mg/kg OC) (cy)							Dredging Designation
	Open-water Option 1, RAL Set including 12 mg/kg OC	Open-water Option 2, RAL Set including 12 mg/kg OC	Open-water Option 3, RAL Set including 12 mg/kg OC	Open-water Option 2, RAL Set including 7.5 mg/kg OC	Open-water Option 3, RAL Set including 7.5 mg/kg OC	Open-water Option 2, RAL Set including 5.0 mg/kg OC	Open-water Option 3, RAL Set including 5.0 mg/kg OC			Open-water Option 1, RAL Set including 12 mg/kg OC	Open-water Option 2, RAL Set including 12 mg/kg OC	Open-water Option 3, RAL Set including 12 mg/kg OC	Open-water Option 2, RAL Set including 7.5 mg/kg OC	Open-water Option 3, RAL Set including 7.5 mg/kg OC	Open-water Option 2, RAL Set including 5.0 mg/kg OC	Open-water Option 3, RAL Set including 5.0 mg/kg OC	
Open-water CMAs																	
Deep Main Body – North and South	190,026	240,710	240,710	263,360	263,360	274,931	274,931	TIN (CAD)	1.5	285,039	361,065	361,065	395,040	395,040	412,397	412,397	Open water
T-18 Berth Area	55,059	56,930	56,930	60,490	60,490	64,132	64,132	TIN (CAD)	1.5	82,589	85,395	85,395	90,735	90,735	96,198	96,198	Open water
T-25 Berth Area	28,755	28,755	28,755	29,391	29,391	32,356	32,356	TIN (CAD)	1.5	43,133	43,133	43,133	44,087	44,087	48,534	48,534	Open water
T-30 Berth Area	18,807	18,807	18,807	22,585	22,585	22,585	22,585	TIN (CAD)	1.5	28,211	28,211	28,211	33,878	33,878	33,878	33,878	Open water
Slip 36	18,121	18,121	18,121	24,477	24,477	27,153	27,153	Average of 5 cores in the slip (EW10-SC57 through -SC61).	1.5	27,181	27,181	27,181	36,716	36,716	40,730	40,730	Open water
Slip 27 Channel	27,685	27,685	27,685	28,792	28,792	29,346	29,346	Average of 2 cores in or near the slip (EW10-SC30 and EW10-SC27).	1.5	41,527	41,527	41,527	43,188	43,188	44,019	44,019	Open water
T-25 Nearshore	4,006	4,006	4,006	4,167	4,167	4,247	4,247	Assume average of 3 cores near area (EW10-SC24, S49, and S50).	1.5	6,010	6,010	6,010	6,250	6,250	6,370	6,370	Open water
T-30 Nearshore	21,381	21,381	21,381	22,236	22,236	22,664	22,664	Average of 4 cores in area (EW10-SC48, EW10-SC50, EW-160, and S45).	1.5	32,071	32,071	32,071	33,354	33,354	33,995	33,995	Open water
T-46 Offshore	n/a	n/a	n/a	3,601	3,601	3,670	3,670	Based on core S30 in the remediation area within T-46.	1.5	n/a	n/a	n/a	5,401	5,401	5,505	5,505	Open water
Shallow Main Body – North	57,033	57,033	66,887	68,655	68,655	88,051	88,051	TIN (CAD)	1.5	85,550	85,550	100,331	102,983	102,983	132,077	132,077	Open water
Shallow Main Body – South	27,375	27,375	36,536	39,830	39,830	44,554	44,554	TIN (CAD)	1.5	41,063	41,063	54,804	59,745	59,745	66,831	66,831	Open water
Sill Reach – West Seattle Bridge	n/a	n/a	11,101	n/a	12,910	n/a	13,158	Average of 2 cores in area (EW10-SC3 and -SC4)	1.5	n/a	n/a	16,651	n/a	19,365	n/a	19,737	Restricted Access
Sill Reach – Low Bridges	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Junction Reach	n/a	n/a	n/a	3,141	3,141	3,201	3,201	Site-wide average dredge depth (no cores in the area).	1.5	n/a	n/a	n/a	4,711	4,711	4,802	4,802	Open water
Former Pier 24 Piling Field	8,873	8,873	14,020	8,873	14,581	8,873	14,861	Estimate 5 feet of removal for capping (Alternatives 1 and 2); Average of 3 adjacent cores (EW10-SC6, -SC8, and -SC9) (Alternative 3).	1.5	13,310	13,310	21,030	13,310	21,871	13,310	22,292	Open water
Mound Area and Slip 27	48,400	48,400	48,400	48,931	48,931	48,931	48,931	5 feet of partial dredging depth plus additional volume to accommodate a 3H:1V slope from the navigation channel.	1.5	72,600	72,600	72,600	73,397	73,397	73,397	73,397	Open water
Coast Guard Nearshore	20,167	20,167	20,167	20,167	20,167	20,167	20,167	5 feet of partial dredging depth estimated	1.5	30,250	30,250	30,250	30,250	30,250	30,250	30,250	Open water
Communication Cable Crossing	16,392	23,232	23,232	23,232	23,232	23,232	23,232	3 feet of removal estimated (Alternatives 2 and 3). Adjustment made in CAD for partial dredging and ENR-nav and ENR-nav areas (Alternative 1).	1.5	24,588	34,848	34,848	34,848	34,848	34,848	34,848	Open water
Subtotal	**542,080**	**601,475**	**636,737**	**671,928**	**690,545**	**718,093**	**737,239**			**813,120**	**902,212**	**955,106**	**1,007,892**	**1,035,818**	**1,077,140**	**1,105,858**	

CMA	Underpier Options A & B	Underpier Options C & C+	Underpier Options D & E, RAL Set including 12 mg/kg OC	Underpier Options D & E, RAL Set including 7.5 mg/kg OC	Underpier Options D & E, RAL Set including 5.0 mg/kg OC	Method for Calculating Neatline Volume	Constructability Factor	Underpier Options A & B	Underpier Options C & C+	Underpier Options D & E, RAL Set including 12 mg/kg OC	Underpier Options D & E, RAL Set including 7.5 mg/kg OC	Underpier Options D & E, RAL Set including 5.0 mg/kg OC	Dredging Designation
Underpier CMA													
Underpier	n/a	7,016	43,940	46,216	48,816	Estimated from underpier cross sections	1.0	n/a	7,016	43,940	46,216	48,816	Underpier
Subtotal	**n/a**	**7,016**	**43,940**	**46,216**	**48,816**			**n/a**	**7,016**	**43,940**	**46,216**	**48,816**	

Notes:
a. Neatline dredge volume represents the idealized dredge prism to the base of contamination without considering constructability factors (see footnote b). Underpier technology options A and B do not include removal. Underpier technology options D and E have the same removal volume and are therefore shown together.
b. The constructability factor accounts for additional dredge volume required to perform dredging in practice, for overdredge depth/volume required to construct stable side-slopes or remove slough material, and for additional volume to design elevation-based dredge prisms. The constructability factor is estimated to be 1.5 for open-water areas. The constructabilty factor is estimated to be 1.0 in underpier areas because dredging is bound by riprap surfaces in these areas.
CAD - computer-aided drafting
CMA - Construction Management Area
cy - cubic yard
mg/kg - milligram per kilogram
n/a - not applicable
OC - organic-carbon normalized
PCB - polychlorinated biphenyl
RAL - remedial action level
TIN - triangular irregular network

Table 2
Removal Volumes for Alternatives

Alternative	Areas			Average Neatline Dredge Depth (feet)	Neatline Volume (cubic yards)	Total Dredge Volume[a]	
	Total Sediment Area (acres)	Remediation Area (acres)	Removal or Partial Removal Area (acres)			Unrounded Dredge Volume (cubic yards)	*Rounded Dredge Volume (cubic yards)*
1A(12)	157	121	97	3.4	542,080	813,120	***810,000***
1B(12)	157	121	97	3.4	542,080	813,120	***810,000***
1C+(12)	157	121	99	3.4	549,096	820,135	***820,000***
2A(12)	157	121	106	3.5	601,475	902,212	***900,000***
2B(12)	157	121	106	3.5	601,475	902,212	***900,000***
2C(12)	157	121	108	3.5	608,491	909,228	***910,000***
2C+(12)	157	121	108	3.5	608,491	909,228	***910,000***
3B(12)	157	121	108	3.7	636,737	955,106	***960,000***
3C+(12)	157	121	110	3.6	643,753	962,121	***960,000***
3D(12)	157	121	118	3.6	680,677	999,046	***1,000,000***
2C+(7.5)	157	132	118	3.6	678,944	1,014,908	***1,010,000***
3C+(7.5)	157	132	120	3.6	697,561	1,042,834	***1,040,000***
3E(7.5)	157	132	131	3.5	736,761	1,082,034	***1,080,000***
2C+(5.0)	157	140	126	3.6	725,109	1,084,155	***1,080,000***
3D(5.0)	157	140	139	3.5	786,055	1,154,675	***1,150,000***
3E(5.0)	157	140	139	3.5	786,055	1,154,675	***1,150,000***

Notes:

a. Total dredge volume is equal to neatline volume times the constructability factor of 1.5 to account for dredge prism design, overdredge, side-slopes, slump material, sedimentation that occurs before remedy implementation, and dredge prism uncertainty.

Bold/italic - Total dredge volumes used in Sections 8, 9, and 10 of Feasibility Study.

Table 3
Remediation Areas and Placement Volumes By Technology Areas

Remedial Technology	Remediation Areas For Alternatives (acres)															
	1A(12)	**1B(12)**	**1C+(12)**	**2A(12)**	**2B(12)**	**2C(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**3D(12)**	**2C+(7.5)**	**3C+(7.5)**	**3E(7.5)**	**2C+(5.0)**	**3D(5.0)**	**3E(5.0)**
Open-water																
Removal	73.2	73.2	73.2	87.9	87.9	87.9	87.9	92.3	92.3	92.3	97.7	102.2	102.1	105.2	109.6	109.6
Removal to the Extent Practicable and Backfill (Communication Cable Crossing Area)	3.3	3.3	3.3	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Removal and Backfill to Existing Contours	0.7	0.7	0.7	0.7	0.7	0.7	0.7	3.5	3.5	3.5	0.8	3.8	3.8	0.8	3.8	3.8
Partial Removal and Cap	12.8	12.8	12.8	12.8	12.8	12.8	12.8	7.3	7.3	7.3	12.8	7.3	7.3	12.8	7.3	7.3
Partial Removal and ENR-nav	7.4	7.4	7.4													
ENR-sill	2.4	2.9	2.9	2.4	2.9	2.9	2.9	1.2	1.2	1.2	3.2	1.3	1.3	3.2	1.3	1.3
ENR-nav	8.7	8.7	8.7													
MNR	0.5			0.5												
Interior Unremediated Area [a]	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	15.1	15.1	15.1	9.2	9.2	9.2
Exterior Unremediated	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	8.5	8.5	8.5	6.9	6.9	6.9
Subtotal	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**143**
Underpier																
Hydraulic Dredging followed by In situ Treatment			1.9				1.9		1.9		1.9	1.9	12.7	1.9		13.4
Hydraulic Dredging						1.9				12.1					13.4	
In situ Treatment		12.1	10.1		12.1	10.1	10.1	12.1	10.1		10.7	10.7		11.5		
MNR	12.1			12.1												
Underpier Unremediated	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.9	1.8	1.8	1.1	1.1	1.1
Subtotal	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**
Total	**157**	**157**	**157**	**157**	**157**	**157**	**157**	**157**	**157**	**157**	**157**	**157**	**157**	**157**	**157**	**157**

Table 3
Remediation Areas and Placement Volumes By Technology Areas

Remedial Technology	Placement Type	Placement Thickness (feet)	Placement Volumes (cubic yards)															
			1A(12)	**1B(12)**	**1C+(12)**	**2A(12)**	**2B(12)**	**2C(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**3D(12)**	**2C+(7.5)**	**3C+(7.5)**	**3E(7.5)**	**2C+(5.0)**	**3D(5.0)**	**3E(5.0)**
Open-water																		
Removal	RMC	0.75	88,580	88,580	88,580	106,341	106,341	106,341	106,341	111,735	111,735	111,735	118,258	123,607	123,592	127,233	132,566	132,566
Removal to the Extent Practicable and Backfill (Communication Cable Crossing Area)	Backfill	4.5	23,931	23,931	23,931	34,593	34,593	34,593	34,593	34,593	34,593	34,593	34,593	34,593	34,593	34,593	34,593	34,593
Removal and Backfill to Existing Contours	Backfill	Average Total Dredge Depth	5,980	5,980	5,914	6,091	6,091	6,029	6,029	30,938	30,615	29,524	7,291	33,256	31,669	7,329	31,819	31,819
Partial Removal and Cap	Armor	1.5	30,931	30,931	30,931	30,931	30,931	30,931	30,931	17,654	17,654	17,654	31,062	17,786	17,786	31,062	17,786	17,786
	Filter	1	20,620	20,620	20,620	20,620	20,620	20,620	20,620	11,769	11,769	11,769	20,708	11,857	11,857	20,708	11,857	11,857
	Isolation	2.5	51,551	51,551	51,551	51,551	51,551	51,551	51,551	29,423	29,423	29,423	51,770	29,643	29,643	51,770	29,643	29,643
Partial Removal and ENR-nav	ENR-nav	1.5	17,980	17,980	17,980													
ENR-sill	ENR-sill	0.75	2,873	3,478	3,478	2,873	3,478	3,478	3,478	1,421	1,421	1,421	3,861	1,562	1,562	3,861	1,562	1,562
ENR-nav	ENR-nav	1.5	21,097	21,097	21,097													
MNR	n/a	n/a																
Interior Unremediated Area [a]	RMC	0.75	22,971	22,971	22,971	22,971	22,971	22,971	22,971	22,971	22,971	22,971	18,223	18,223	18,223	11,091	11,091	11,091
Exterior Unremediated	n/a	n/a																
Subtotal			**286,512**	**287,117**	**287,051**	**275,971**	**276,576**	**276,513**	**276,513**	**260,506**	**260,183**	**259,092**	**285,766**	**270,526**	**268,925**	**287,647**	**270,916**	**270,916**
Underpier																		
Hydraulic Dredging followed by In situ Treatment	In situ Treatment	0.25			782				782		782		782	782	5,113	782		5,401
Hydraulic Dredging	n/a	0																
In situ Treatment	In situ Treatment	0.25		4,867	4,085		4,867	4,085	4,085	4,867	4,085		4,331	4,331		4,619		
MNR	n/a	n/a																
Underpier Unremediated	n/a	n/a																
Subtotal			**0**	**4,867**	**4,867**	**0**	**4,867**	**4,085**	**4,867**	**4,867**	**4,867**	**0**	**5,113**	**5,113**	**5,113**	**5,401**	**0**	**5,401**
Total			**286,512**	**291,984**	**291,918**	**275,971**	**281,443**	**280,598**	**281,380**	**265,373**	**265,049**	**259,092**	**290,879**	**275,640**	**274,038**	**293,048**	**270,916**	**276,318**

Notes:

a. Interior unremediated areas are sediment areas with no remedial action level exceedances, but which are surrounded by areas to be remediated.

ENR-nav - enhanced natural recovery applied in the navigation channel and deep-draft berthing areas

ENR-sill - enhanced natural recovery used in the Sill Reach

MNR - monitored natural recovery

n/a - not applicable

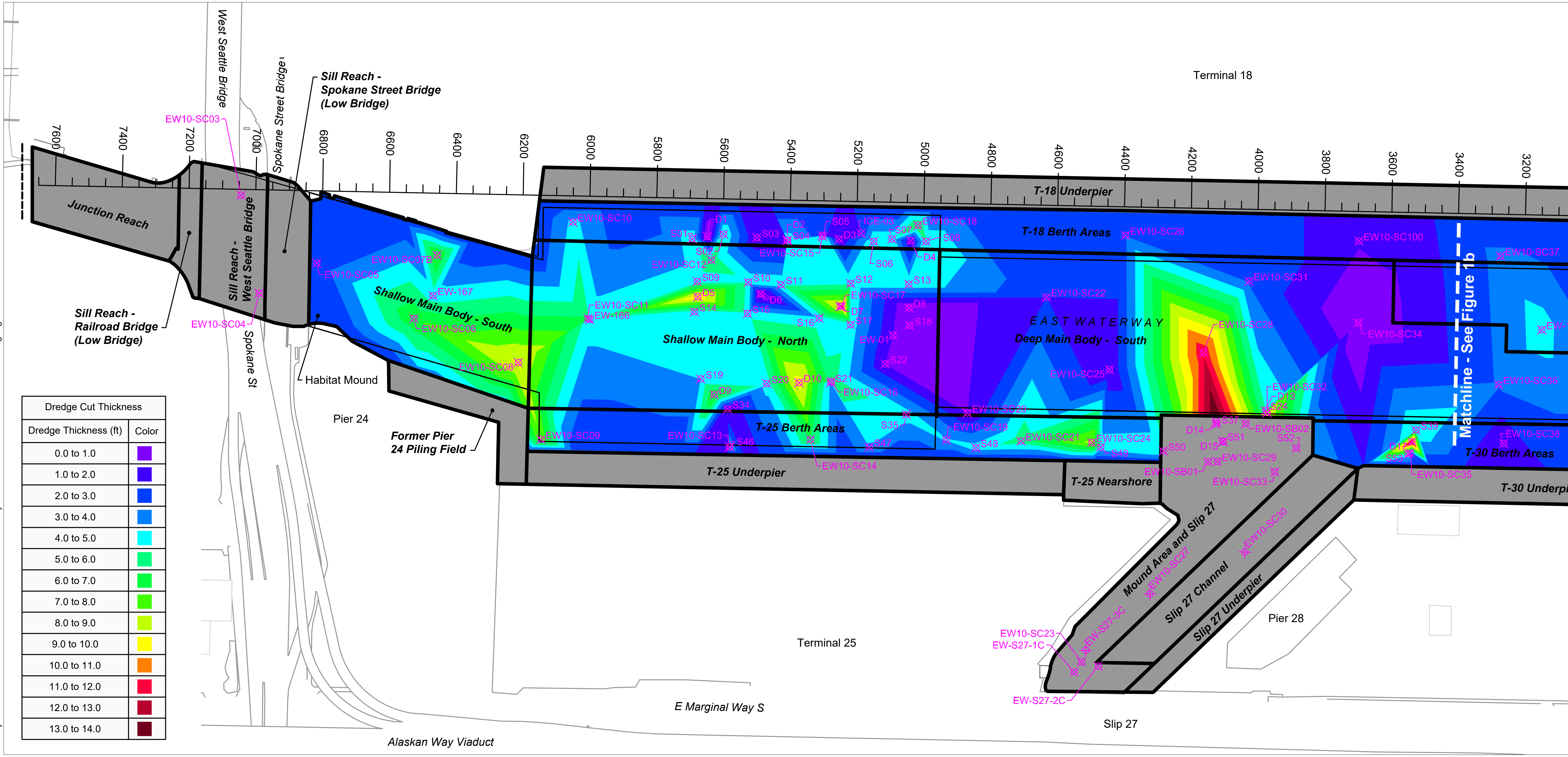
RMC - residuals management cover

Table 4
Placement Volumes for Alternatives

Alternative (PCB RAL mg/kg OC)	Placement Volume by Remedial Technology (cy)								Total Placement Volume	
	RMC	Backfill	ENR-sill	ENR-nav	Capping			In situ Treatment	Unrounded Placement Volume (cy)	*Rounded Placement Volume (cy)*
					Armor	Filter	Isolation			
1A(12)	111,551	29,911	2,873	39,076	30,931	20,620	51,551	0	286,512	***290,000***
1B(12)	111,551	29,911	3,478	39,076	30,931	20,620	51,551	4,867	291,984	***290,000***
1C+(12)	111,551	29,845	3,478	39,076	30,931	20,620	51,551	4,867	291,918	***290,000***
2A(12)	129,312	40,685	2,873	0	30,931	20,620	51,551	0	275,971	***280,000***
2B(12)	129,312	40,685	3,478	0	30,931	20,620	51,551	4,867	281,443	***280,000***
2C(12)	129,312	40,622	3,478	0	30,931	20,620	51,551	4,085	280,598	***280,000***
2C+(12)	129,312	40,622	3,478	0	30,931	20,620	51,551	4,867	281,380	***280,000***
3B(12)	134,706	65,531	1,421	0	17,654	11,769	29,423	4,867	265,373	***270,000***
3C+(12)	134,706	65,208	1,421	0	17,654	11,769	29,423	4,867	265,049	***270,000***
3D(12)	134,706	64,118	1,421	0	17,654	11,769	29,423	0	259,092	***260,000***
2C+(7.5)	136,480	41,884	3,861	0	31,062	20,708	51,770	5,113	290,879	***290,000***
3C+(7.5)	141,830	67,849	1,562	0	17,786	11,857	29,643	5,113	275,640	***280,000***
3E(7.5)	141,814	66,262	1,562	0	17,786	11,857	29,643	5,113	274,038	***270,000***
2C+(5.0)	138,323	41,922	3,861	0	31,062	20,708	51,770	5,401	293,048	***290,000***
3D(5.0)	143,656	66,413	1,562	0	17,786	11,857	29,643	0	270,916	***270,000***
3E(5.0)	143,656	66,413	1,562	0	17,786	11,857	29,643	5,401	276,318	***280,000***

Notes:
cy - cubic yards
ENR-nav - enhanced natural recovery applied in the navigation channel and deep-draft berthing areas
ENR-sill - enhanced natural recovery used in the Sill Reach
mg/kg - milligram per kilogram
OC - organic-carbon normalized
PCB - polychlorinated biphenyl
RAL - remedial action level
RMC - residuals management cover

FIGURES



K:\Projects\0003-Port of Seattle\POS SD-101 East Waterway SRI-FS\0003-RP-020-Iso-June 2016.dwg Figure 1a

Aug 07, 2017 10:44am tgriga

HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet

NOTES:

1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. TIN = Triangulated Irregular Network

LEGEND:

East Waterway Study Boundary

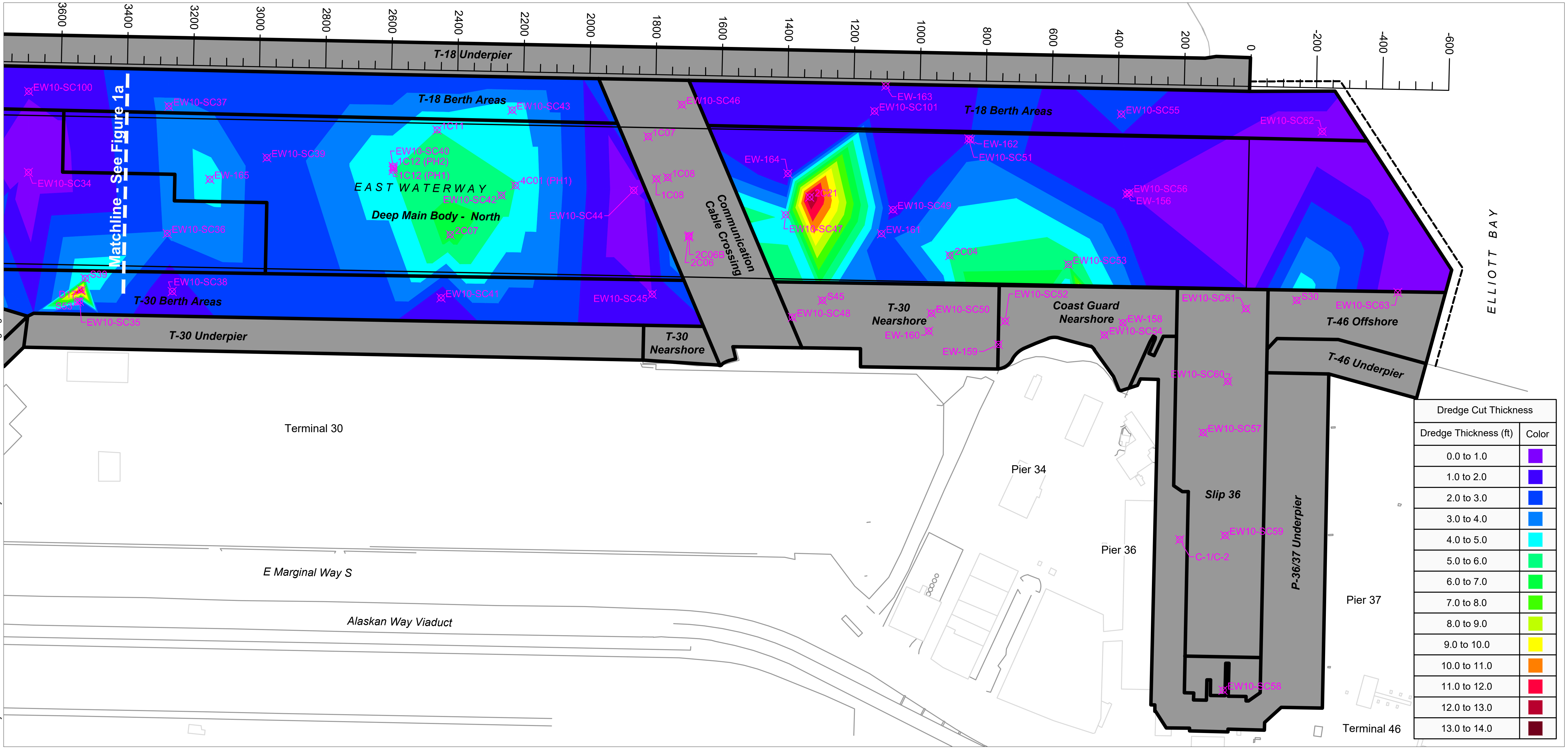
Construction Management Areas

CMA Areas not included in TIN

EW-S27-2C Sediment Core

0 300
Scale in Feet

Figure 1a
Full Removal TIN Neatline Isopach (All RALs, PCBs = 12 mg/kg OC)
Feasibility Study - Appendix F
East Waterway Study Area



Dredge Cut Thickness	
Dredge Thickness (ft)	Color
0.0 to 1.0	
1.0 to 2.0	
2.0 to 3.0	
3.0 to 4.0	
4.0 to 5.0	
5.0 to 6.0	
6.0 to 7.0	
7.0 to 8.0	
8.0 to 9.0	
9.0 to 10.0	
10.0 to 11.0	
11.0 to 12.0	
12.0 to 13.0	
13.0 to 14.0	

HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet

NOTES:
1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. TIN = Triangulated Irregular Network

LEGEND:

East Waterway Study Boundary

Construction Management Areas

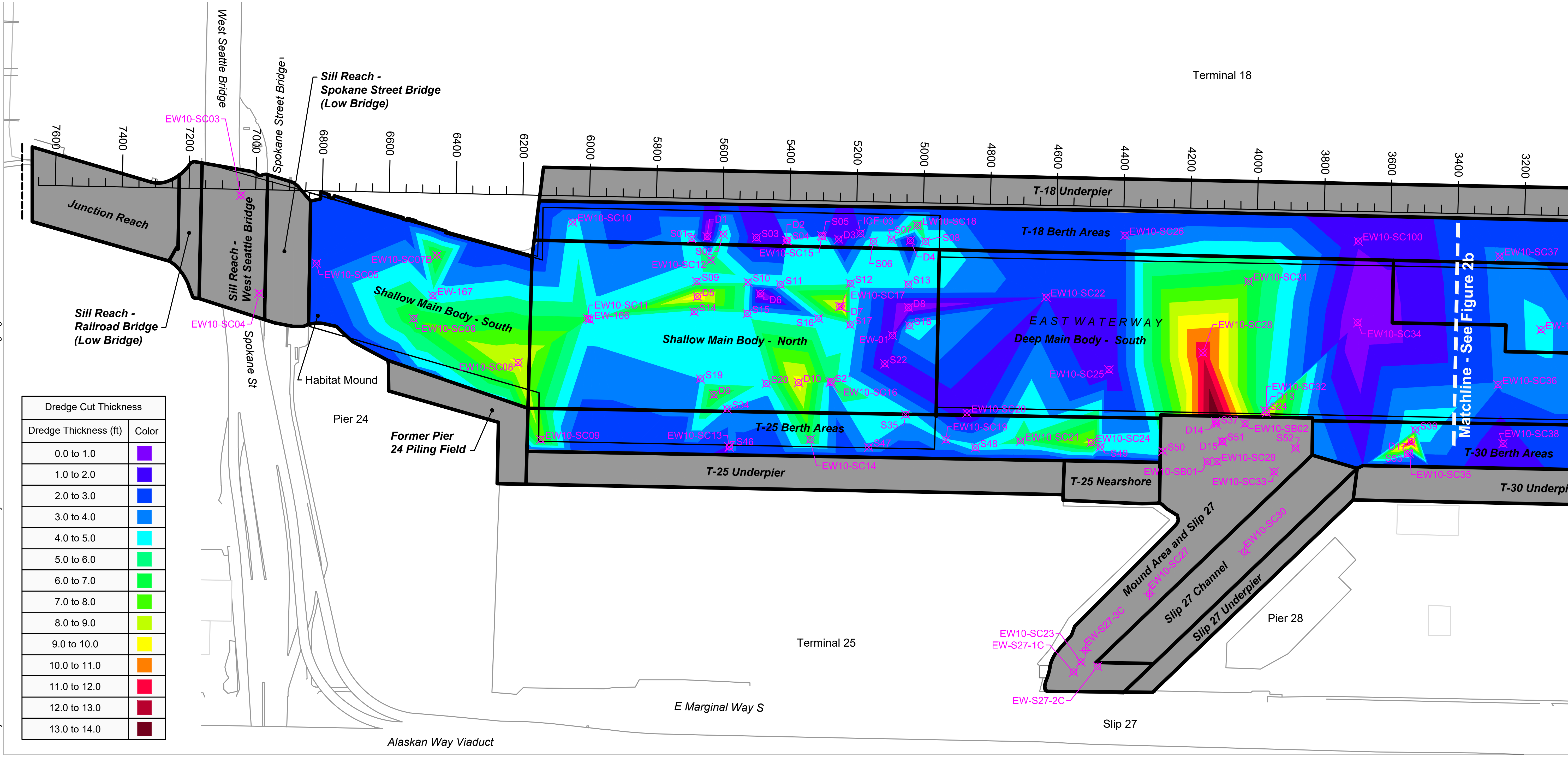
CMA Areas not included in TIN

EW-S27-2C Sediment Core

0 300 Scale in Feet

N

Figure 1b
Full Removal TIN Neatline Isopach (All RALs, PCBs = 12 mg/kg OC)
Feasibility Study - Appendix F
East Waterway Study Area



HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet

NOTES:

1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. TIN = Triangulated Irregular Network

LEGEND:

East Waterway Study Boundary

Construction Management Areas

CMA Areas not included in TIN

EW-S27-2C Sediment Core

K:\Projects\0003-Port of Seattle\POS SD-101 East Waterway SRI-FS\0003-RP-020-Iso-June 2016.dwg Figure 2a

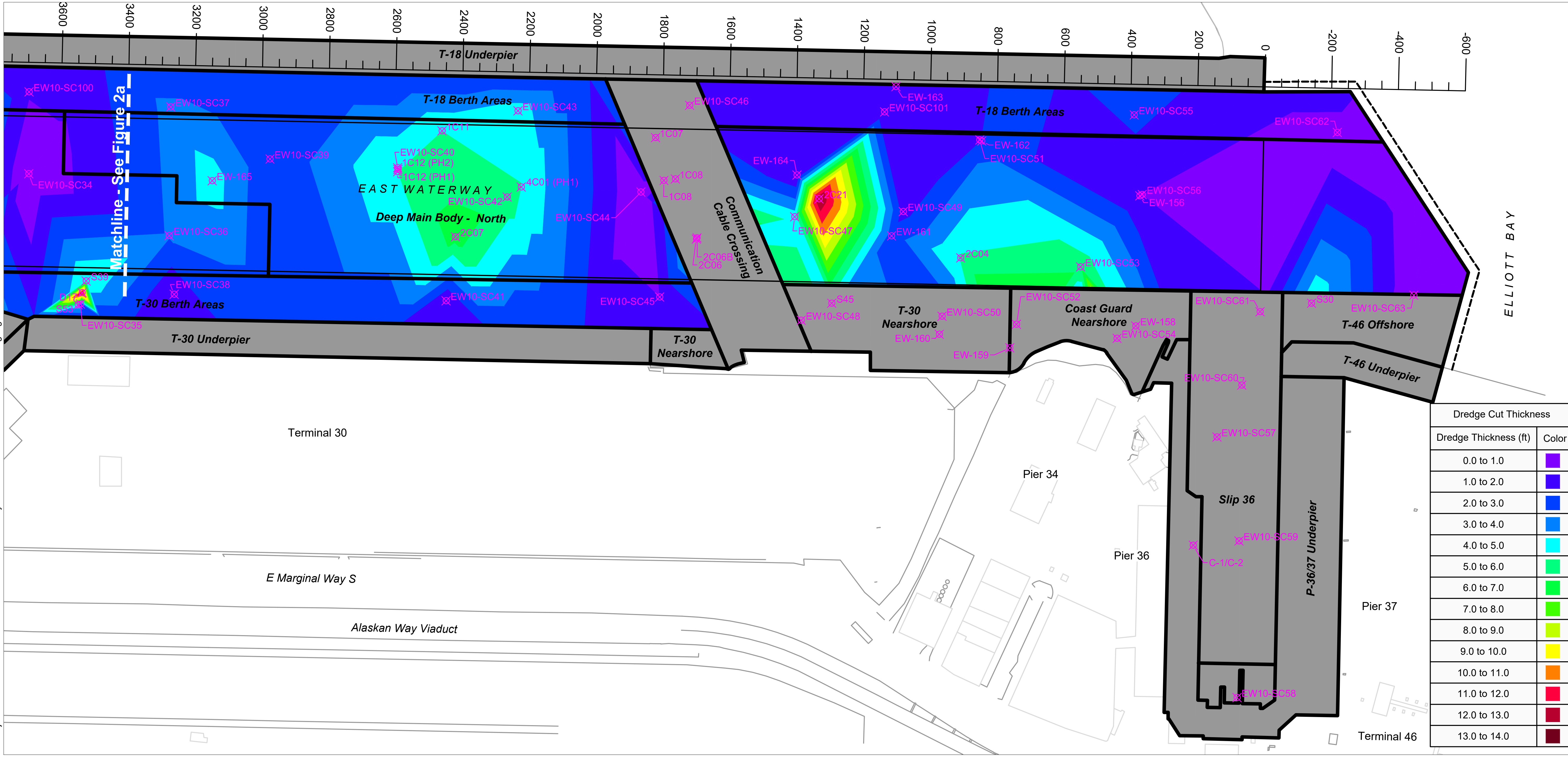
Aug 07, 2017 10:44am tgriga

Figure 2a

Full Removal TIN Neatline Isopach (All RALs, PCBs = 7.5 mg/kg OC)

Feasibility Study - Appendix F

East Waterway Study Area



K:\Projects\0003-Port of Seattle\POS SD-101 East Waterway SRI-FS\0003-RP-020-Iso-June 2016.dwg Figure 2b

Aug 07, 2017 10:44am tgriga

HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet

NOTES:

1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. TIN = Triangulated Irregular Network

LEGEND:

East Waterway Study Boundary

Construction Management Areas

CMA Areas not included in TIN

EW-S27-2C Sediment Core

0 300 Scale in Feet

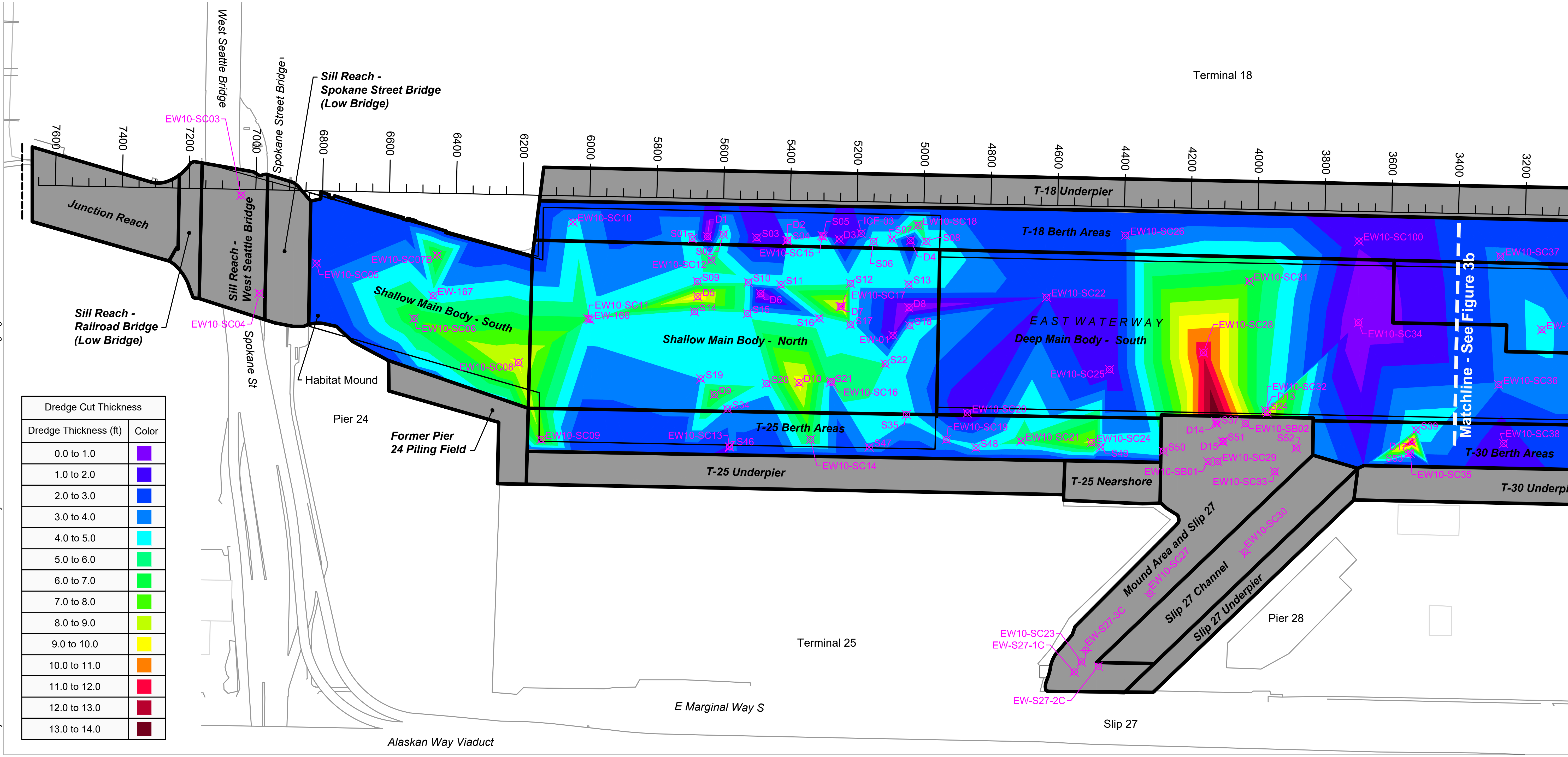
N

Figure 2b

Full Removal TIN Neatline Isopach (All RALs, PCBs = 7.5 mg/kg OC)

Feasibility Study - Appendix F

East Waterway Study Area



HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet

NOTES:

1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. TIN = Triangulated Irregular Network

LEGEND:

East Waterway Study Boundary

Construction Management Areas

CMA Areas not included in TIN

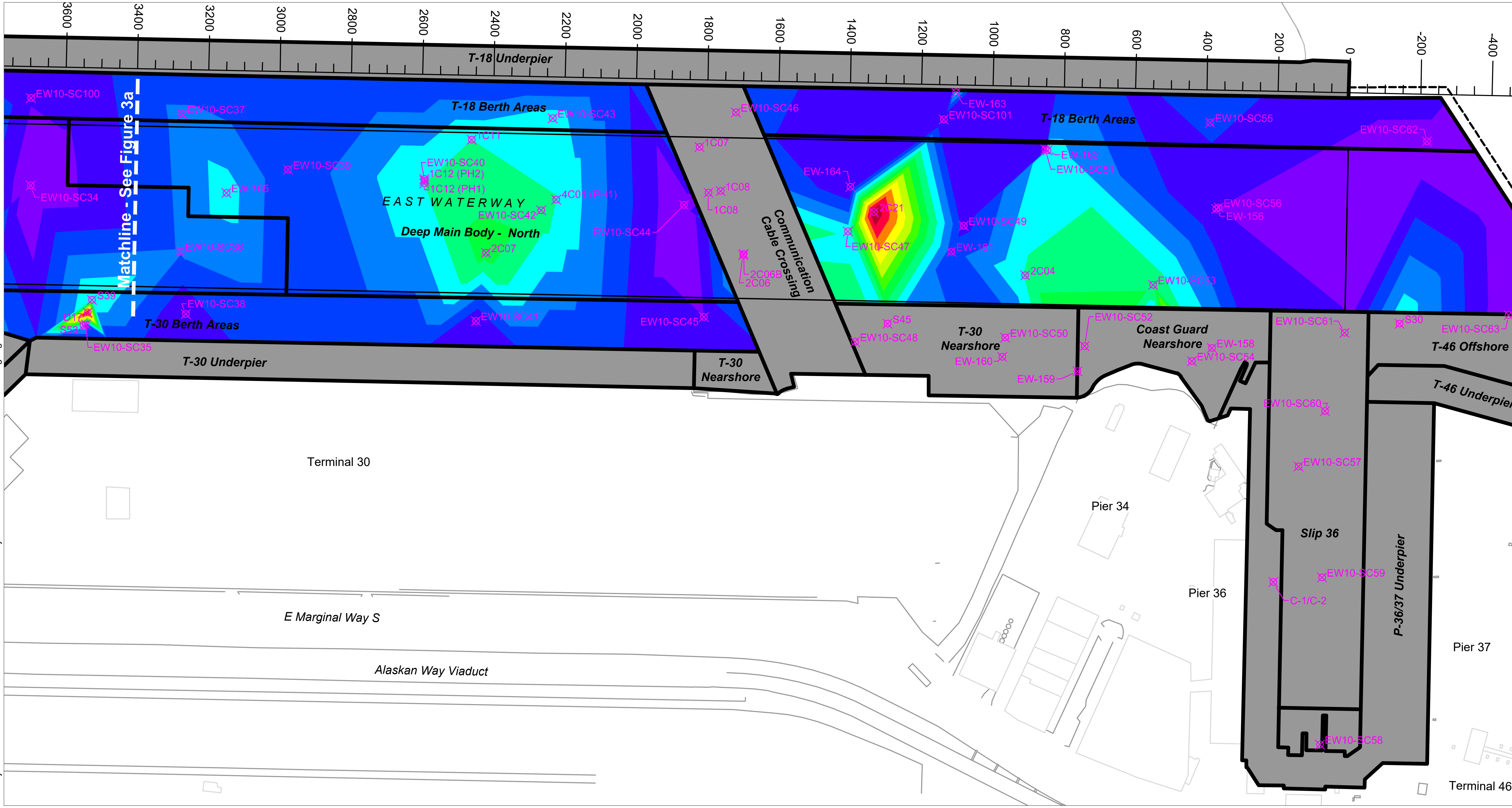
EW-S27-2C Sediment Core

0 300 Scale in Feet

N

Figure 3a
Full Removal TIN Neatline Isopach (All RALs, PCBs = 5.0 mg/kg OC)
Feasibility Study - Appendix F
East Waterway Study Area

K:\Projects\0003-Port of Seattle\POS SD-101 East Waterway SRI-FS\0003-RP-020-Iso-June 2016.dwg Figure 3a
Aug 07, 2017 10:44am tgriga



Dredge Cut Thickness

Dredge Thickness (ft)	Color
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1.0 to 2.0	
2.0 to 3.0	
3.0 to 4.0	
4.0 to 5.0	
5.0 to 6.0	
6.0 to 7.0	
7.0 to 8.0	
8.0 to 9.0	
9.0 to 10.0	
10.0 to 11.0	
11.0 to 12.0	
12.0 to 13.0	
13.0 to 14.0	

K:\Projects\0003-Port of Seattle\POS SD-101 East Waterway SRI-FS\0003-RP-020-Iso-June 2016.dwg Figure 3b

Aug 07, 2017 10:44am tgriga

HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet

NOTES:

1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. TIN = Triangulated Irregular Network

LEGEND:

East Waterway Study Boundary

Construction Management Areas

CMA Areas not included in TIN

EW-S27-2C Sediment Core

0 300 Scale in Feet

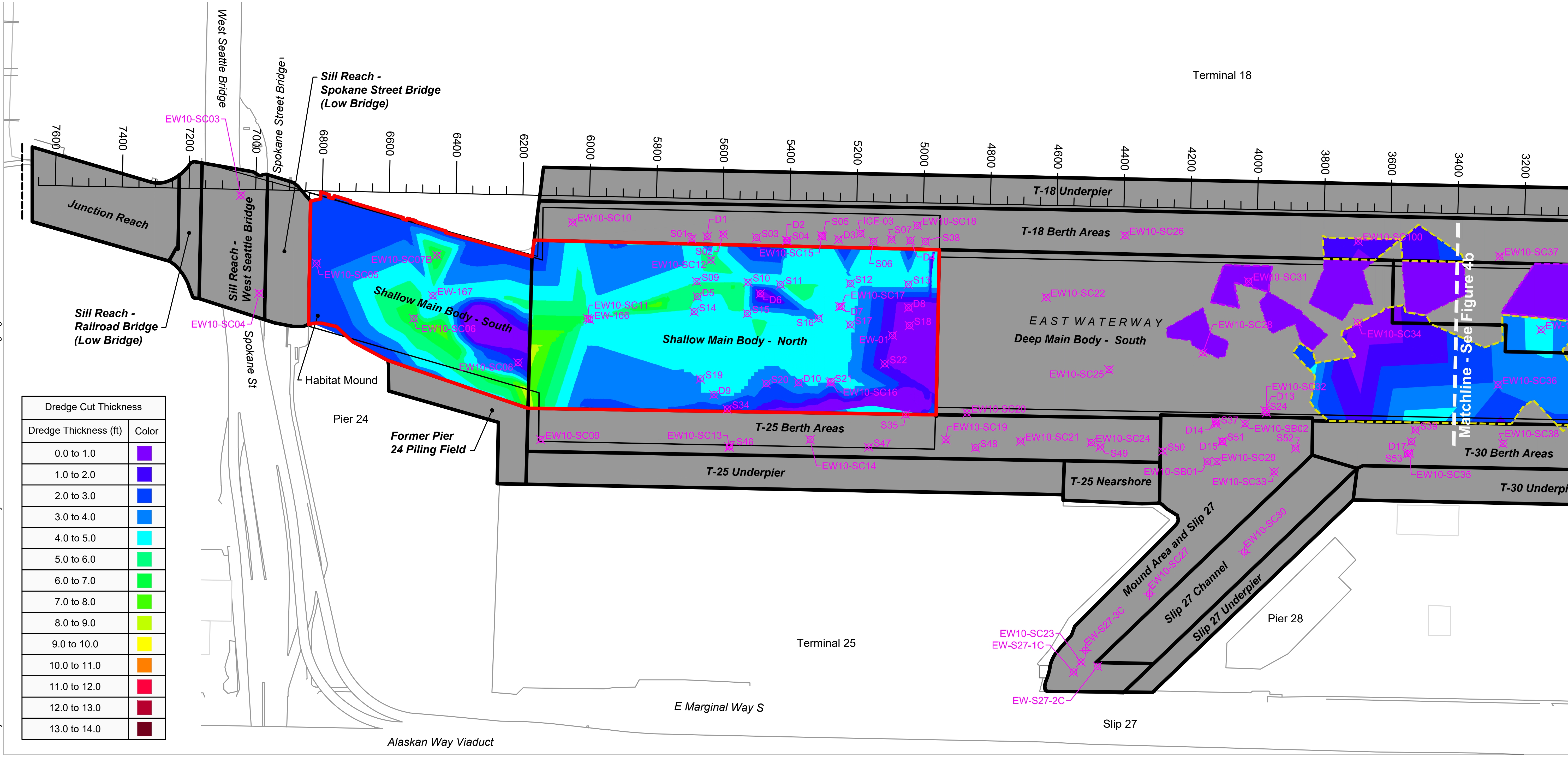
N

Figure 3b

Full Removal TIN Neatline Isopach (All RALs, PCBs = 5.0 mg/kg OC)

Feasibility Study - Appendix F

East Waterway Study Area



K:\Projects\0003-Port of Seattle\POS SD-101 East Waterway SRI-FS\0003-RP-020-Iso-June 2016.dwg Figure 4a

Aug 07, 2017 10:44am tgriga

HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet

NOTES:
1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. TIN = Triangulated Irregular Network

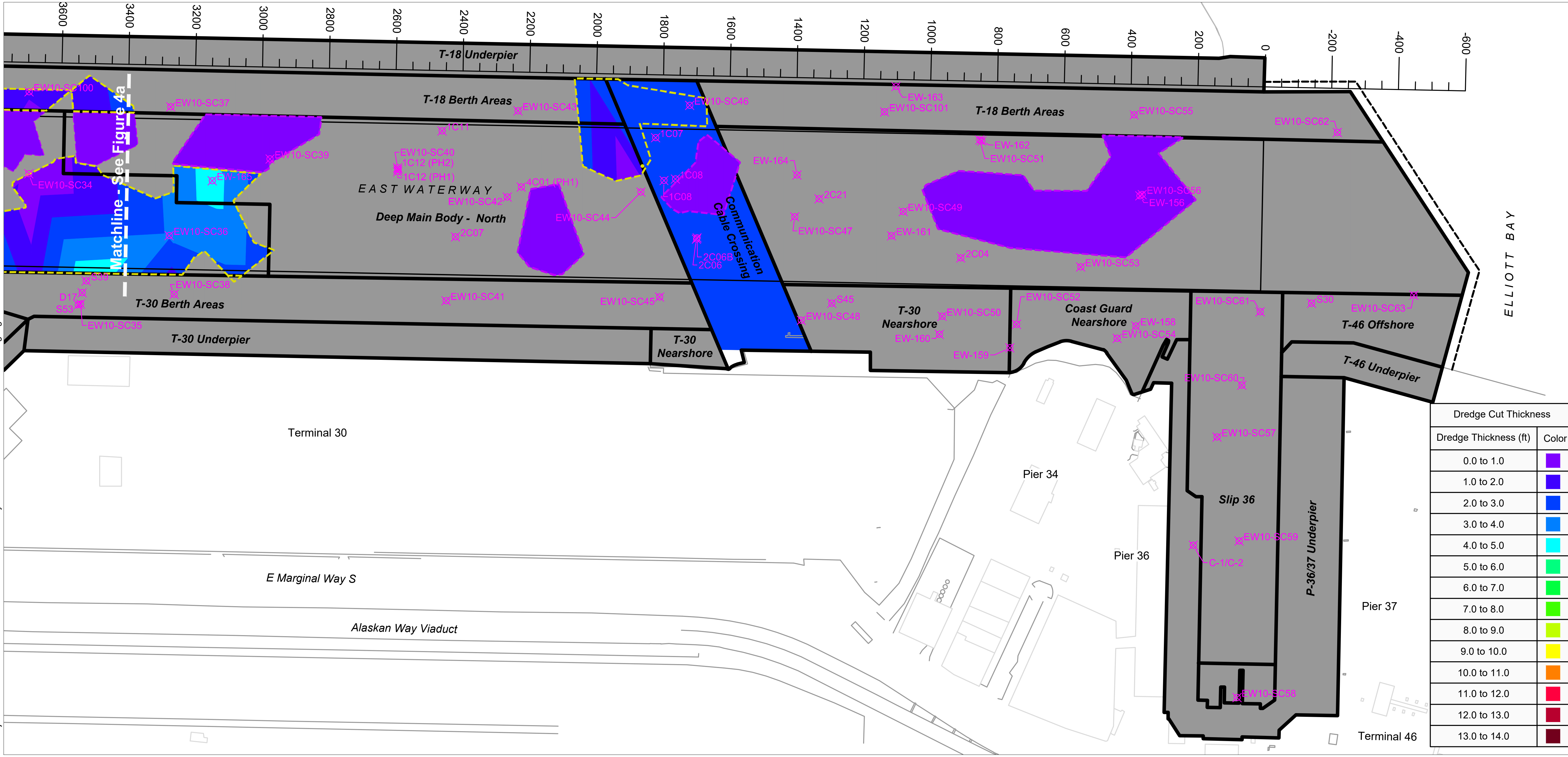
LEGEND:

- East Waterway Study Boundary
- Construction Management Areas
- EW-S27-2C Sediment Core
- CMA Areas not included in Partial Removal TIN
- Partial Removal and Capping Area (Removal Depth Shown; Applicable to Open-water Technology Groups 1 and 2)
- ENR-nav Area (No Removal; Applicable to Open-water Technology Group 1)
- Partial Removal and ENR-nav Area (Removal Depth Shown; Applicable to Open-water Technology Group 1)

0 300
Scale in Feet

N

Figure 4a
Partial Removal TIN Neatline Isopach
Feasibility Study - Appendix F
East Waterway Study Area



Dredge Cut Thickness	
Dredge Thickness (ft)	Color
0.0 to 1.0	
1.0 to 2.0	
2.0 to 3.0	
3.0 to 4.0	
4.0 to 5.0	
5.0 to 6.0	
6.0 to 7.0	
7.0 to 8.0	
8.0 to 9.0	
9.0 to 10.0	
10.0 to 11.0	
11.0 to 12.0	
12.0 to 13.0	
13.0 to 14.0	

K:\Projects\0003-Port of Seattle\POS SD-101 East Waterway SRI-FS\0003-RP-020-Iso-June 2016.dwg Figure 4b

Aug 07, 2017 10:44am tgriga

HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet

NOTES:
1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. TIN = Triangulated Irregular Network

LEGEND:

East Waterway Study Boundary

Construction Management Areas

EW-S27-2C Sediment Core

CMA Areas not included in Partial Removal TIN

ENR-nav Area (No Removal; Applicable to Open-water Technology Group 1)

Partial Removal and ENR-nav Area (Removal Depth Shown; Applicable to Open-water Technology Group 1)

0 300 Scale in Feet

N

Figure 4b
Partial Removal TIN Neatline Isopach
Feasibility Study - Appendix F
East Waterway Study Area

APPENDIX G – MONITORING
EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

Prepared for
Port of Seattle

Prepared by
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June 2019

TABLE OF CONTENTS

List of Tables

1 INTRODUCTION

This appendix presents the rationale and conceptual structure for a multi-component East Waterway (EW) Operable Unit (OU) monitoring program. The conceptual monitoring program serves solely as the basis for estimating the costs of monitoring associated with each remedial alternative in Appendix E of the Feasibility Study (FS). Because it is solely for the limited purpose of costing, the conceptual monitoring program uses several simplifying assumptions and is not intended to represent the specific scope, timing, and duration of monitoring that will eventually occur in the EW. The final cleanup will include a monitoring program with a statistical basis for demonstrating compliance with applicable criteria and standards and the success of remedial alternatives, as well as provisions for adjusting the monitoring program to support adaptive management decisions. These details will be determined in the Record of Decision and during remedial design.

The monitoring program described herein is sufficiently broad, detailed, and consistent with guidance to fulfill FS-level scope and cost estimation objectives. The elements of the monitoring program described in this appendix include the following:

- Pre-construction baseline monitoring
- Construction monitoring and confirmational sampling
- Operations and maintenance monitoring
- Long-term monitoring

This appendix sets forth assumptions regarding quantities and frequencies of sampling and reporting that form the basis for cost estimation. Table 1 presents a summary of monitoring assumptions by monitoring category and matrix. Table 2 presents additional detail on assumptions for long-term monitoring for each remedial alternative. The sampling scope in Table 2 is used as the basis for estimating monitoring costs in Appendix E of the FS.

2 MONITORING OBJECTIVES

The general goals of monitoring are to support effective remedial design, verify that design goals have been met, and measure effectiveness following construction. The monitoring objectives specific to the monitoring elements are provided in the following bullets:

- **Pre-construction baseline monitoring:** Establish baseline conditions for comparison to post-construction performance monitoring results.
- **Construction monitoring and confirmational sampling:** Protect human health and the environment during construction activities, comply with regulatory requirements, verify that construction is performed to specifications, and assess the need for construction contingencies, such as the placement of residuals management cover following dredging.
- **Operations and maintenance monitoring:** Measure the post-construction and long-term performance of remedial technologies. This type of monitoring targets the performance of specific remedial technologies (e.g., cap stability).
- **Long-term monitoring:** Measure the post-construction and long-term performance of remediation toward achievement of remedial action objectives (RAOs) that ensure protection of human health and the environment. This type of monitoring targets parameters that indicate performance relative to the RAOs (e.g., site-wide average concentrations).

3 PRE-CONSTRUCTION BASELINE MONITORING

The objective of baseline monitoring is to establish a site-wide basis for comparing pre- and post-construction conditions. Baseline monitoring occurs before construction commences and has some overlap with remedial design sampling and data collection (Section 8.1.3 of the FS). Data for baseline monitoring is described in this section and summarized in Tables 1 and 2. Costs for pre-construction baseline monitoring presented in Appendix E of the FS are based on the approximate costs associated with the sampling program described herein. Baseline sampling is assumed to have similar scope as long-term monitoring in years 5, 10, 15, and 20 for the alternatives (Table 2). Baseline monitoring also includes a site-wide bathymetric survey; however, this is included as a separate line item in the cost estimate.

One aspect of pre-construction baseline monitoring is to measure seafood tissue concentrations. For this evaluation, additional tissue data are assumed to be collected to establish a site-wide composite seafood tissue concentration, represented by various species and tissue types for site-wide consumption scenarios (e.g., English sole [*Parophrys vetulus*], shiner surfperch [*Cymatogaster aggregate*], crab [*Cancer magister* or *Cancer productus*], and clams such as butter clams [*Saxidomus gigantean*]).

Another aspect of pre-construction baseline monitoring is sediment chemistry, including surface sediment concentrations for the key exposure areas of the site: site-wide (RAOs 1, 2, and 4) and in potential clamming areas (RAO 2) and on a point-by-point basis (RAO 3). Sampling media and densities are assumed to be consistent with Long-term Monitoring, described in Sections 5 and 6 of this appendix, respectively, and include surface sediment chemistry (site-wide), surface sediment porewater (only in situ treatment and enhanced natural recovery [ENR] areas), surface water, and subsurface sediment chemistry (only in situ treatment areas).

4 CONSTRUCTION MONITORING AND CONFIRMATIONAL SAMPLING

Construction monitoring during remediation is used to protect human health and the environment during construction activities, and to evaluate whether the project is being constructed in accordance with plans, specifications, and permit requirements. Construction monitoring will be determined during remedial design and permitting, and is assumed to include the following:

- Daily contractor progress bathymetric surveys in removal and placement areas.
- Daily field-based water quality monitoring in the immediate vicinity of the remediation activities to demonstrate compliance with water quality certification requirements (e.g., physical measures such as turbidity) to determine whether the resuspension of contaminated sediments and their downgradient movement are being adequately controlled.
- Intermittent collection of downcurrent water column samples for chemical analyses (e.g., polychlorinated biphenyls [PCBs]). The need for chemical analyses will be based on the screening results from the daily field-based water quality monitoring during dredging and sand placement activities. A portion of these samples will be submitted for chemical analyses regardless of field-based monitoring results.
- Bathymetric surveys, assumed to be site-wide events, one before and one after each construction season.

Costs for construction monitoring are based on daily and annual contractor costs for surveys and daily costs for water quality monitoring (see Appendix E of the FS).

The objective of confirmational sampling is to demonstrate whether, after construction, the cleanup complies with project requirements and design specifications (e.g., surface sediment contaminant concentrations are below the remedial action levels [RALs]; minimum ENR thickness meets requirements in specifications), and to assess the need for construction contingencies such as residuals management cover. Confirmational sampling is assumed to occur prior to contractor demobilization as phases of work are completed. Costs for confirmational sampling are assumed to be the same as those for year 1 Operations and Maintenance Monitoring and Long-term Monitoring for the remedial alternatives (Appendix E).

5 OPERATIONS AND MAINTENANCE MONITORING

The purpose of operations and maintenance monitoring is to assess the effectiveness of the remedial technologies (e.g., the stability of a sediment cap, or the rate of natural recovery in monitored natural recovery [MNR] areas). Operations and maintenance monitoring is summarized in Tables 1 and 2 and includes monitoring shortly after construction (i.e., year 1 post-construction) and monitoring in the long term (i.e., for 20 years following construction). Costs for operations and maintenance monitoring presented in Appendix E of the FS are based on the approximate costs associated with the sampling program described herein. This includes technology-specific sampling for performance of specific locations. Sampling media and densities in years 1, 5, 10, 15, and 20 post-construction are assumed to include surface sediment chemistry (all technology areas), surface sediment porewater (only in situ treatment and ENR areas), and subsurface sediment chemistry (only in situ treatment areas) (Table 1). Analysis will occur for the analytes listed in Table 1. Bathymetric survey and physical inspections (e.g., diver inspections) will also occur in capping, ENR, and in situ treatment areas in years 1, 5, 10, 15, and 20 post-construction. In year 3 post-construction, operations and maintenance monitoring is assumed to be performed only within in situ treatment, ENR, and MNR areas, where additional time-trend data (i.e., in addition to years 1 and 5) will be valuable for understanding contaminant trends.

6 LONG-TERM MONITORING

Long-term monitoring for tissue is assumed to be similar in scope to baseline sampling (described in Section 3), so that monitoring results can be compared. Tissue concentrations are anticipated to be measured as five composite samples for English sole, perch, crab, and intertidal clams in years 1, 3, 5, 10, 15, and 20 following construction (20 composite samples). As discussed in Section 7.2.6, dredging residuals could result in elevated fish and shellfish tissue concentrations due to impacts to the water column; therefore, tissue samples measured within 2 years of construction are more likely to be influenced by construction related releases than post-construction sediment conditions. Surface water sampling is also assumed to be similar in scope to baseline sampling and measured in years 1, 5, 10, 15, and 20 following construction. The final monitoring framework will be developed in remedial design.

Sediment chemistry will include surface sediment samples for the key exposure areas of the site: site-wide (RAOs 1, 2, 3 and 4) and in clamming areas (RAO 2). Achievement of RAO 3 is measured by site-wide sampling on a point-by-point basis, whereas other RAOs are based on 95% upper confidence limit on the mean (UCL95) based on site-wide or clamming area-wide sampling. Sampling will occur at the appropriate points of compliance (top 10 centimeters [cm] site-wide for all RAOs, and top 25 cm in intertidal areas for the RAO 2 portion for tribal clamming). For the purpose of defining the monitoring scope, long-term monitoring has been combined with operations and maintenance monitoring in Tables 1 and 2.

TABLES

Table 1
Long-term Monitoring Assumptions for Remedial Alternatives

Monitoring Category	Surface Sediment[a]	Porewater[b]	Subsurface Sediment[c]	Tissue[d]	Surface Water[e]	Bathymetric Survey and Physical Inspections
Pre-construction Baseline Sampling	Baseline sampling includes surface sediment, subsurface sediment, tissue, and bathymetric surveys for the purpose of establishing site-wide conditions. Assumed to have similar scope as years 5, 10, 15, and 20 Operations and Maintenance Monitoring and Long-term Monitoring for the alternatives.					
Construction Monitoring and Confirmational Sampling	Determined during remedial design, assumed to include water quality monitoring during removal and placement activities, surface sediment, and physical inspection. Confirmation sampling assumed to have similar scope as year 1 Operations and Maintenance Monitoring and Long-term Monitoring for the alternatives.					
Operations and Maintenance Monitoring and Long-term Monitoring						
Year 1						
Site-wide	Sampling in technology areas provides site-wide coverage	n/a	n/a	5 composites for 3 species (sole, crab, and perch)	2 locations, 2 depths, 2 measurements (8 total samples)	--
Clamming areas	Sampling in technology areas provides coverage	n/a	n/a	5 composites of clams	n/a	n/a
Open-water						
Dredging	1 sample/4 acres	--	--	n/a	n/a	n/a
Capping	1 sample/2 acres			n/a	n/a	Bathymetric survey and physical inspections
ENR		1 sample/acre		n/a	n/a	
No action	1 sample/4 acres	--		n/a	n/a	n/a
Underpier and Under Low Bridges						
Dredging	1 sample/2 acres	--	--	n/a	n/a	n/a
In situ treatment	1 sample/acre	1 sample/acre	1 core/acre	n/a	n/a	Bathymetric survey and physical inspections
ENR		--	--	n/a	n/a	
MNR				n/a	n/a	n/a
No action	1 sample/2 acres			n/a	n/a	n/a
Year 3						
Site-wide	--	n/a	n/a	5 composites for 3 species (sole, crab, and perch)	--	--
Clamming areas	--	n/a	n/a	5 composites of clams	n/a	n/a
Open-water						
Dredging	--	--	--	n/a		
Capping						
ENR	2 samples/2 acres	1 sample/acre				
No action	--	--				
Underpier and Under Low Bridges						
Dredging	--	--	--	n/a		
In situ treatment	1 sample/acre	1 sample/acre	1 core/acre			
ENR		--	--			
MNR						
No action	--					
Years 5, 10, 15, and 20						
Site-wide	Sampling in technology areas provides site-wide coverage	n/a	n/a	5 composites for 3 species (sole, crab, and perch)	2 locations, 2 depths, 2 measurements (8 total samples)	--
Clamming areas	Sampling in technology areas provides coverage	n/a	n/a	5 composites of clams	n/a	n/a
Open-water						
Dredging	1 sample/4 acres	--	--	n/a	n/a	n/a
Capping	1 sample/2 acres			n/a	n/a	Bathymetric survey and physical inspections
ENR		1 sample/acre		n/a	n/a	
No action	1 sample/4 acres	--		n/a	n/a	n/a
Underpier and Under Low Bridges						
Dredging	1 sample/2 acres	--	--	n/a	n/a	n/a
In situ treatment	1 sample/acre	1 sample/acre	1 cores/acre	n/a	n/a	Bathymetric survey and physical inspections
ENR		--	--	n/a	n/a	
MNR				n/a	n/a	n/a
No action	1 sample/2 acres			n/a	n/a	n/a

Notes:
-- = no monitoring
n/a = not applicable
1. Monitoring assumptions are for Feasibility Study cost purposes; monitoring framework will be developed in design.
a. Assume all samples are analyzed for total PCBs (as Aroclors), arsenic, cPAHs, and the 29 benthic risk-driver COCs, and associated conventional parameters (e.g., TOC, grain size, and percent solids), and 25% of samples are analyzed for dioxins/furans, PCB congeners, and other COCs. Sediment toxicity would be performed as necessary (assume 25% of samples).
b. Assume all porewater samples are analyzed for PCB congeners and dioxins/furans.
c. Assume cores consist of 4 samples each, analyzed for total PCBs (as Aroclors), arsenic, cPAHs, all SMS contaminants, and associated conventional parameters (e.g., TOC, grain size, and percent solids), and 25% of samples are analyzed for dioxins/furans, PCB congeners, and other COCs.
d. Assume all composite tissue samples are analyzed for arsenic, cPAHs, and PCBs (as Aroclors) and 25% of samples are analyzed for dioxins/furans, PCB congeners, and other COCs.
e. Assume surface water is analyzed only for TBT (only surface water COC).
COC - contaminant of concern
ENR - enhanced natural recovery
MNR - monitored natural recovery
SMS - Sediment Management Standards
TBT - tributyltin
TOC - total organic carbon

Table 2
Long-term Monitoring for Remedial Alternatives

Alternative (PCB RAL in mg/kg OC)	Surface Sediment Samples (All Areas)	Porewater Samples (ENR and In Situ Treatment Areas)	Cores (In Situ Treatment Areas)	Tissue Composite Samples (5 Composites for Each of Sole, Crab, Perch, and Clam)	Surface Water Samples (2 Locations, 2 Depths, 2 Measurements)	Bathymetric Survey and Physical Inspection Events
Pre-construction Baseline Sampling. Baseline sampling includes surface sediment, subsurface sediment, tissue, and bathymetric surveys for the purpose of establishing site-wide conditions. Assumed to have similar scope as years 5, 10, 15, and 20 Operations and Maintenance Monitoring and Long-term Monitoring for the alternatives.						
Construction Monitoring and Confirmational Sampling. Determined during remedial design, assumed to include water quality monitoring during removal and placement activities, surface sediment, and physical inspection. Confirmation sampling assumed to have similar scope as year 1 Operations and Maintenance Monitoring and Long-term Monitoring for the alternatives.						
Operations and Maintenance Monitoring and Long-term Monitoring						
Year 1						
No Action	39	0	0	0	0	0
1A(12)	62	0	0	20	8	1
1B(12)	62	13	13	20	8	1
1C+(12)	62	13	13	20	8	1
2A(12)	58	0	0	20	8	1
2B(12)	58	13	13	20	8	1
2C(12)	57	11	11	20	8	1
2C+(12)	58	13	13	20	8	1
3B(12)	56	13	13	20	8	1
3C+(12)	56	13	13	20	8	1
3D(12)	50	0	0	20	8	1
2C+(7.5)	56	13	13	20	8	1
3C+(7.5)	54	13	13	20	8	1
3E(7.5)	55	13	13	20	8	1
2C+(5.0)	58	14	14	20	8	1
3D(5.0)	49	0	0	20	8	1
3E(5.0)	56	14	14	20	8	1
Year 3						
No Action	0	0	0	0	0	0
1A(12)	31	0	0	20	0	0
1B(12)	31	13	13	20	0	0
1C+(12)	31	13	13	20	0	0
2A(12)	23	0	0	20	0	0
2B(12)	23	13	13	20	0	0
2C(12)	21	11	11	20	0	0
2C+(12)	23	13	13	20	0	0
3B(12)	19	13	13	20	0	0
3C+(12)	19	13	13	20	0	0
3D(12)	6	0	0	20	0	0
2C+(7.5)	23	13	13	20	0	0
3C+(7.5)	19	13	13	20	0	0
3E(7.5)	20	13	13	20	0	0
2C+(5.0)	24	14	14	20	0	0
3D(5.0)	6	0	0	20	0	0
3E(5.0)	20	14	14	20	0	0
Years 5, 10, 15, and 20						
No Action	39	0	0	0	0	0
1A(12)	62	0	0	20	8	1
1B(12)	62	13	13	20	8	1
1C+(12)	62	13	13	20	8	1
2A(12)	58	0	0	20	8	1
2B(12)	58	13	13	20	8	1
2C(12)	57	11	11	20	8	1
2C+(12)	58	13	13	20	8	1
3B(12)	56	13	13	20	8	1
3C+(12)	56	13	13	20	8	1
3D(12)	50	0	0	20	8	1
2C+(7.5)	56	13	13	20	8	1
3C+(7.5)	54	13	13	20	8	1
3E(7.5)	55	13	13	20	8	1
2C+(5.0)	58	14	14	20	8	1
3D(5.0)	49	0	0	20	8	1
3E(5.0)	56	14	14	20	8	1

Notes:

1. Monitoring assumptions are for Feasibility Study cost purposes; monitoring framework will be developed in design.
2. For the action alternatives, sampling scope is based on the sampling densities in Table 1. For the No Action Alternative, sampling is based on one surface sediment sample every 4 acres of sediment approximately every 5 years.

ENR - enhanced natural recovery
mg/kg - milligram per kilogram
OC - organic carbon
PCB - polychlorinated biphenyl
RAL - remedial action level

APPENDIX H – REMAINING SUBSURFACE CONTAMINATION

EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

Prepared for

Port of Seattle

Prepared by

Anchor QEA, LLC

720 Olive Way, Suite 1900

Seattle, Washington 98101

June 2019

TABLE OF CONTENTS

List of Figures

1 INTRODUCTION

This appendix presents a series of figures depicting East Waterway (EW) Operable Unit (OU) subsurface sediment exceedances of the remedial action levels (RALs)[1]. Also shown are the sediment quality standards (SQS) and the cleanup screening levels (CSL) exceedances for all Washington State Sediment Management Standards (SMS) chemicals to provide additional characterization of the subsurface sediments. Figures 1a-c through 6a-c provide a reference for each remedial alternative, illustrating the remedial technology selection, dredge depths, and the locations of subsurface contamination left in place after construction. This text describes the generation of the figures.

[1] For some risk driver COCs the RAL is equal to the SQS.

2 METHODS

For presentation purposes, the nine remedial alternatives are grouped into four groups. The No Action alternative, is unique and has its own set of figures (Figures 1a-c). Remedial Alternatives 1A(12), 1B(12), and 1C+(12) have the same remedial technologies for all areas except under piers and, therefore, are shown on the same set of figures (Figures 2a-c). Alternatives 2B(12) and 2C+(12) are also unique and have their own set of figures (Figures 3a-c). Alternatives 3B(12) and 3C+(12) have the same remedial technologies in open-water areas and share the same set of figures (Figures 4a-c). Finally, Alternatives 2C+(7.5) and 3E(7.5) are both unique and have their own sets of figures (Figures 5a-c and Figures 6a-c, respectively).

Core intervals representing sediment that has been dredged subsequent to sampling were not presented on figures. The rules and methods for data manipulation (e.g., determining exceedances, summing non-detects, etc.) are consistent with the EW SRI (Windward and Anchor QEA 2014). For core intervals with field duplicates, the average of the two results was used for RAL comparison, consistent with methods used in the SRI, and the parent sample is labeled on the figures.

The sampled core intervals on Figures 1a-c through 6a-c are coded based on RAL exceedances (yellow), and benthic CSL exceedances (red). RALs are presented in Section 6 of the Feasibility Study (FS) in Table 6-1, and consist of nine indicator SMS chemicals (for which the RAL is the SQS), and three other chemicals (dioxins/furans, carcinogenic polycyclic aromatic hydrocarbons [cPAHs], and tributyltin [TBT]). Although CSL is not an action level in subsurface sediments, CSL exceedances (considering all benthic contaminants of concern [COCs]) are shown on the figures to indicate locations with higher contaminant concentrations (CSL exceedances are also RAL exceedances[2]). If at least one RAL is exceeded

[2] With the exception of ICE-03 in the 0-1 foot interval, which does not exceed RALs for any of the nine indicator SMS chemicals, but does exceed the CSL for cadmium (which does not have a RAL). This exception does not affect the vertical extent of contamination because a deeper interval exceeds for PCBs (and thus drives remediation in this location). This exception does not affect the horizontal extent of contamination because of RAL exceedances in nearby surface sediment samples. All other sample intervals that exceed CSL for any COC also exceed for one or more of the indicator SMS chemicals with RALs.

in a core interval, that interval is labeled as greater than RALs and is identified as the depth of contamination for that core. Using the RALs, which include nine indicator SMS chemicals that represent all 29 risk driver COC SMS chemicals, to determine the depth of contamination does not exclude any exceedances of the SMS chemicals. Therefore, the RALs are appropriate for determining the depth of contamination.

A subset of RALs is based on SQS (see Section 6 of the FS). Many of these are based on carbon-normalized concentrations; however, carbon normalization is only considered valid within a specified range of total organic carbon (TOC) content. Sediment samples with TOC contents from 0.5% to 4% were TOC-normalized for comparison to SMS benthic criteria. The lower bound value of 0.5% TOC is provided by the Washington State Department of Ecology (Michelsen and Bragdon-Cook 1993), and the upper bound value of 4% is consistent with the value used in the LDW FS (AECOM 2012). For samples with TOC content outside of that range, the dry weight concentrations were compared to the lowest apparent effects threshold (LAET), which is functionally equivalent to the SQS, and the second lowest LAET (2LAET), which is functionally equivalent to the CSL.

cPAHs have one RAL site-wide and one RAL in intertidal clamming areas. For this analysis, cores with surface elevations above -4 feet mean lower low water (MLLW) were compared to the intertidal RAL (for potential clamming areas), and cores with surface elevations below -4 feet MLLW were compared to the site-wide RAL.

The dredging depths in removal areas were determined in a manner consistent with calculating the dredging volume in Appendix F, as follows:

- If the deepest RAL exceedance was just above an interval without a detected RAL exceedance, then the dredge depth was assumed to be at the contact between the two intervals.
- If the deepest RAL exceedance was just above an interval that was not analyzed, then the un-analyzed interval was assumed to be a RAL exceedance, and the dredge depth was assumed to be the top of the next interval without a detected RAL exceedance.
- If the deepest sample interval was a RAL exceedance, than the dredge depth was assumed to be the depth of the core plus an additional 1 foot.

- If the core had no RAL exceedances, then no dredging was assumed (note that the volume estimate in Appendix F assumes a 1-foot minimum dredging depth in removal areas with only surface sediment exceeding RALs).

The cores depicted in the figures were not compaction corrected, whereas the volumes in Appendix F included a compaction correction for cores with sampling percent recovery information available. In addition, the cores depicted in the figures do not include additional removal for overdredging or stable side slopes, and represent the neatline dredging depths.

The dredging depths in partial removal and capping areas were determined in a manner consistent with calculating the dredging volume in Appendix F as follows:

- In the Shallow Main Body Reach, the partial dredging depth was calculated to fit a 5-foot isolation cap and provide appropriate clearance for navigation. Partial dredging was assumed to extend to -38 feet MLLW in the Shallow Main Body – South, and -48 feet MLLW in the Shallow Main Body – North, as described in Section 7 of the FS. If the calculated partial dredging depth exceeded the depth of contamination, then the dredging depth was assumed to be the depth of contamination. Note that in some deep water locations, no partial dredging is needed, and capping without partial dredging would be specified during design.
- In the Mound Area, Slip 27 Head and Shoreline, and the Coast Guard Nearshore, the partial dredging depth was assumed to be 5 feet, to accommodate a 5-foot cap with the surface at original grade. If the calculated partial dredging depth of 5 feet exceeded the depth of contamination, then the dredging depth was assumed to be the depth of contamination.

The dredging depths in partial dredging and ENR-nav areas were determined in a manner consistent with calculating the dredging volume in Appendix F as follows:

- In the Deep Main Body Reach, Communication Cable Crossing area, and Deep Draft Berthing Areas, the partial dredging depth was calculated to fit an assumed 1.5-foot-thick ENR-nav layer. Partial dredging was assumed to extend to -54 feet MLLW, approximately 3 feet below the maintenance dredging depths. Where the partial dredging depth is greater than the thickness of contamination, the thickness of contamination was considered the partial dredging depth.

3 DISCUSSION

The remediation area presented on each figure is based on the methodology described in Section 6 of the FS, by considering exceedances of RALs in surface sediment (including surface sediment toxicity) throughout the entire OU and the upper 2 feet of subsurface sediment for all areas north of the Spokane Street Bridge. The upper 2 feet in these areas are considered because of potential propwash forces that could expose subsurface sediments. These propwash forces do not occur under and south of the Spokane Street Bridge. In general, elevated subsurface contaminant concentrations are co-located with areas of elevated surface sediment concentrations, which are being actively remediated.

Relatively deeper deposits of contaminated sediment occur in the Mound Area and the Shallow Main Body Reach. These areas generally have subsurface sediment concentrations that are greater than the surface sediment concentrations (see FS Section 2.11.2.2), and have not been recently dredged for maintenance purposes (see FS Figure 2-22). In the Shallow Main Body Reach, some cores exceed RALs deeper than 2 feet below mudline, but do not exceed RALs in the upper 2 feet. Cores that were sampled in intervals larger than the upper 2 feet of sediment (e.g., sample intervals from 0 to 4 feet) were not used for establishing the remediation area. Eight of these cores (i.e., S01, S11, S13, S15, S16, S20, S30, and S47) contain a sample interval with concentrations above RALs within an unremediated area. These were not included in the remediation area because surface sediment concentrations are below RALs, and/or toxicity testing passed SQS criteria[3]. In addition, mixing depths from propeller wash (propwash) in the area of these cores is estimated to be 0.7 feet (with the exception of S30 and S47; see FS Figure 5-4), which suggests that mixing is not likely to occur across the full length of these intervals. Therefore, contamination present below the surface is unlikely to be exposed due to propwash.

Areas with relatively thin deposits of contaminated sediment are found in the Deep Main Body Reach and adjacent berths. These areas have been more recently dredged, resulting in

[3] See FS Section 6 for more details on the development of the remediation footprints. For benthic risk-drivers, toxicity testing results trump chemistry results, except for polygons that exceed the SQS for PCBs and arsenic. PCBs and arsenic are also a human health COC and so RAL exceedances are always included in the remediation footprint.

thinner depths of contaminated sediment. For example, RALs are exceeded in surface sediment, but not in any of the following cores: EW10-SC38, EW10-SC20, EW10-SC25, EW10-SC41, EW10-SC45, EW10-SC46, EW-164, EW10-SC101, EW-156, and EW10-SC56, indicating surficial contamination only.

The extent of remediation will be re-evaluated and modified as necessary during remedial design. Potential additional dredging volumes as a result of expansion of the dredging footprint are accounted for in the FS in the 50% dredging volume design factor described in Appendix F.

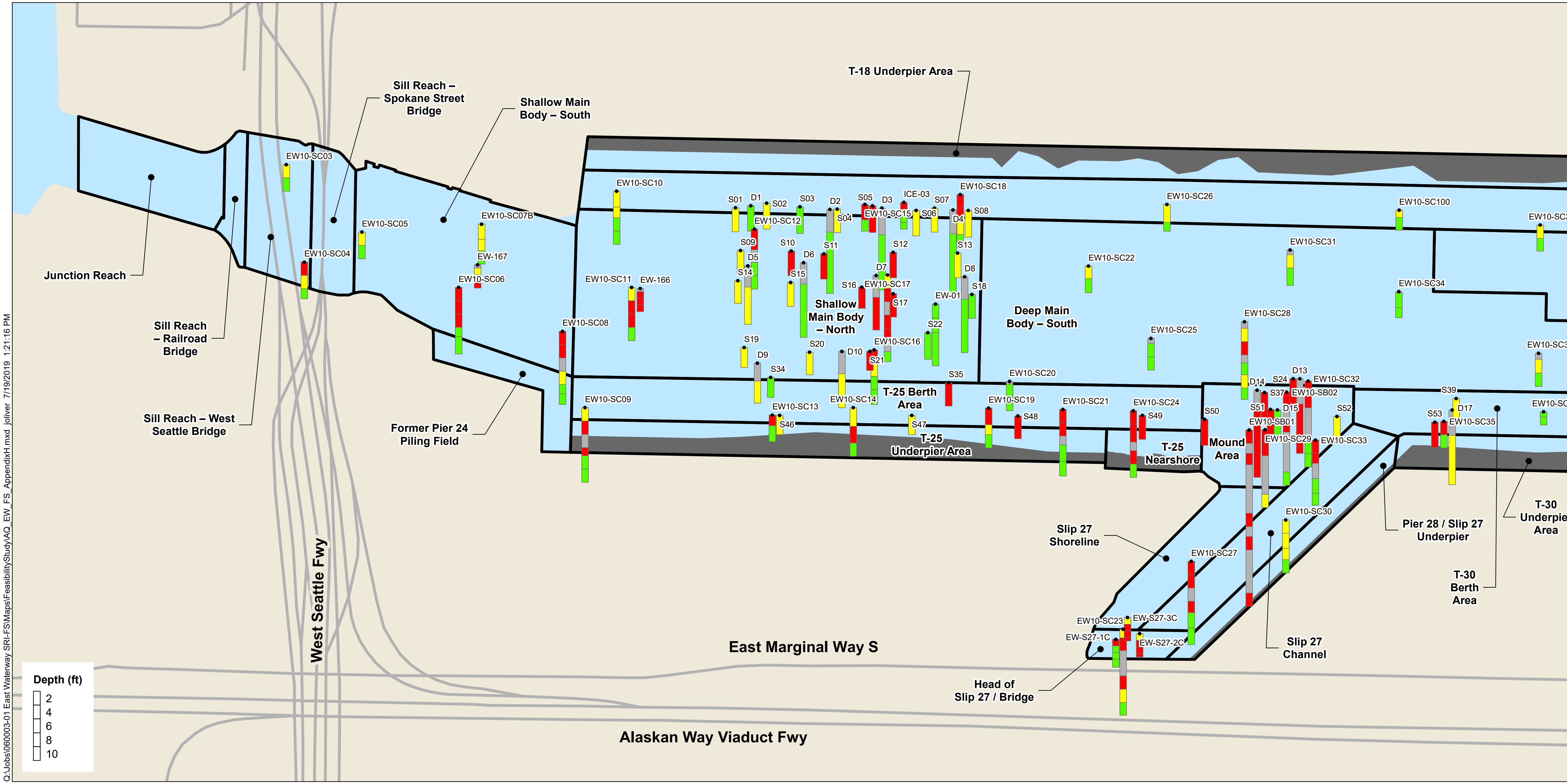
4 REFERENCES

AECOM, 2012. Feasibility Study, Lower Duwamish Waterway, Seattle, Washington. Final Report. Prepared for Lower Duwamish Waterway Group. October 2012.

Michelsen, T.C., and K. Bragdon-Cook, 1993. Technical Information Memorandum: Organic Carbon Normalization of Sediment Data. Washington State Department of Ecology, Olympia, WA.

Windward and Anchor QEA, 2014. Supplemental Remedial Investigation. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Final. January 2014.

FIGURES



No Action
Riprap (No Action)
Exceedance Status
≤ RAL(12) and ≤ SQS
> RAL(12) or > SQS
> CSL
Interval not Analyzed
CMA Boundaries

0 150 300 450 600
Scale in Feet

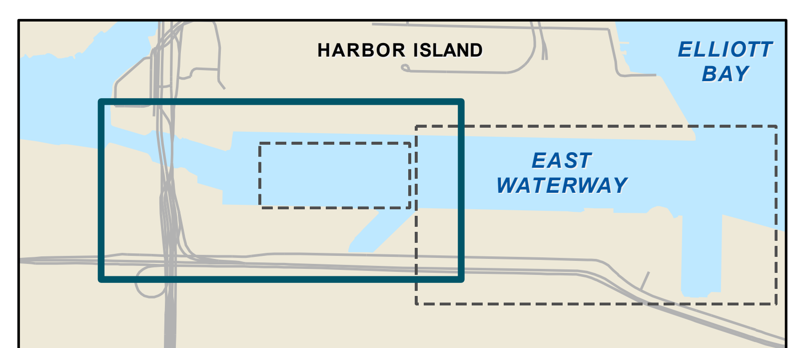
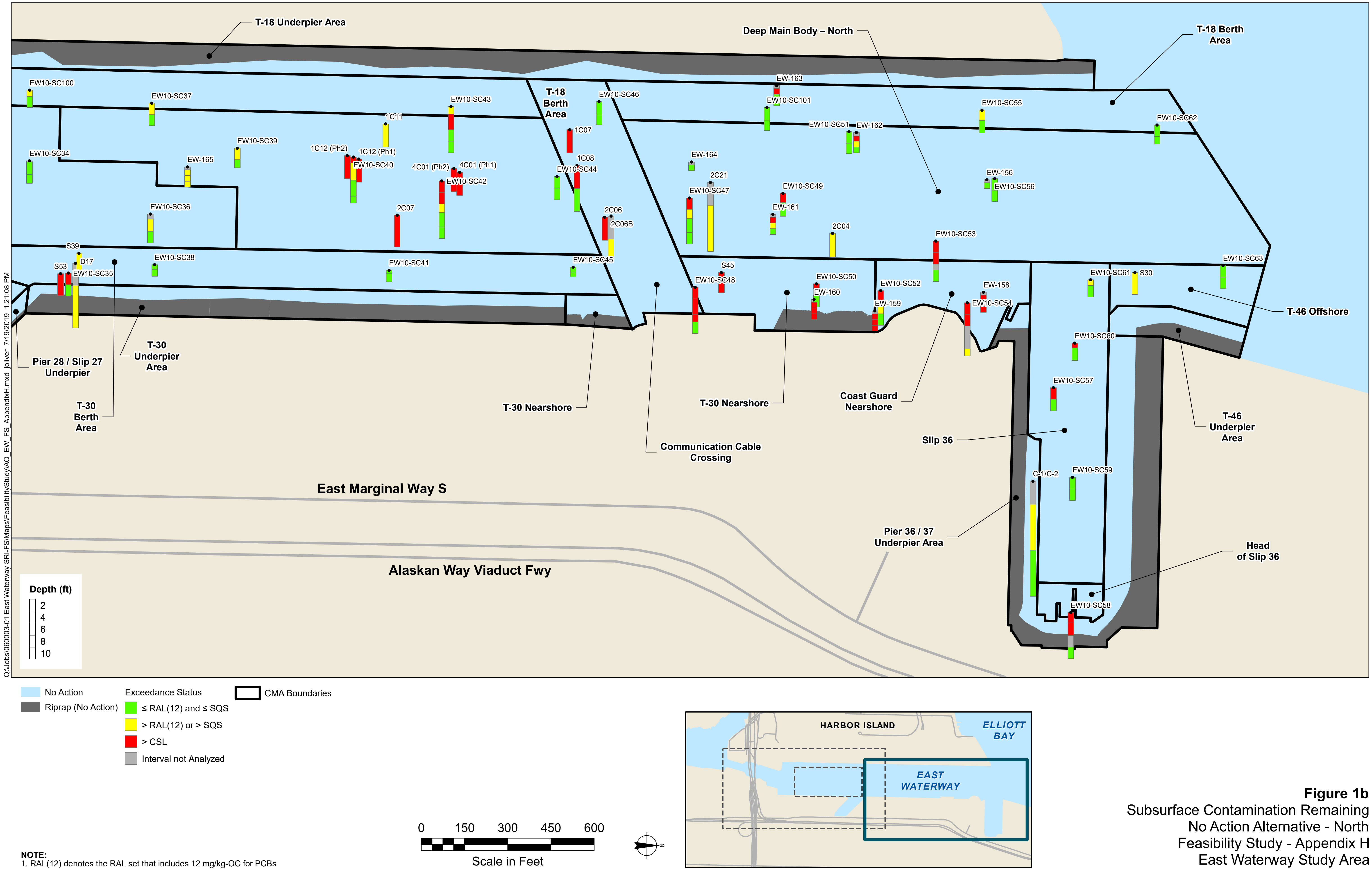


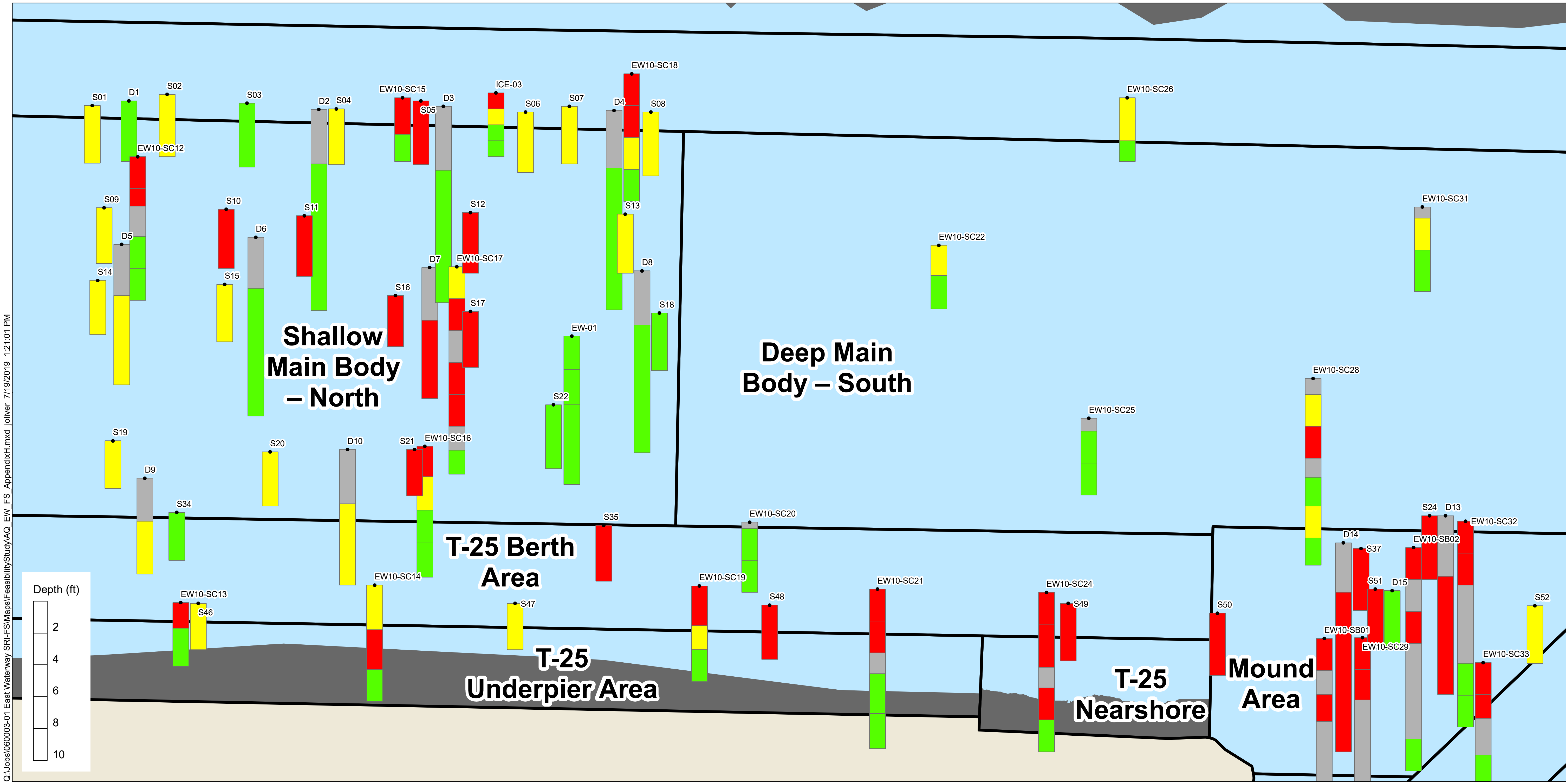
Figure 1a
Subsurface Contamination Remaining
No Action Alternative - South
Feasibility Study - Appendix H
East Waterway Study Area

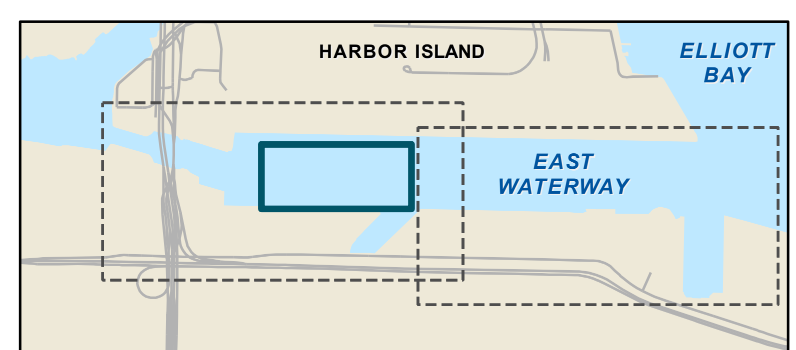
NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs



NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs

Figure 1b
Subsurface Contamination Remaining
No Action Alternative - North
Feasibility Study - Appendix H
East Waterway Study Area





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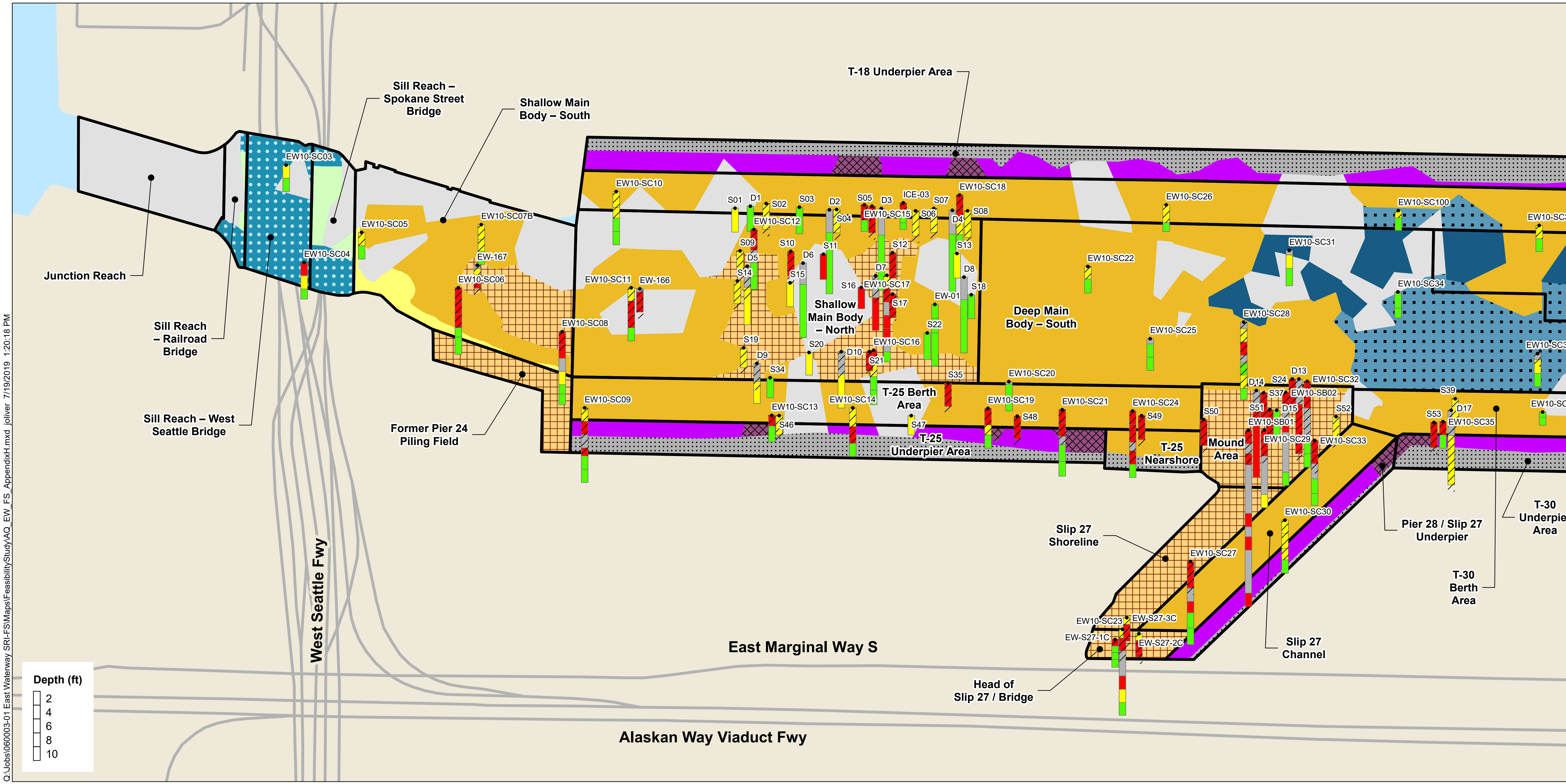
NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs

Figure 1c
Subsurface Contamination Remaining
No Action Alternative - Detail, South
Feasibility Study - Appendix H
East Waterway Study Area



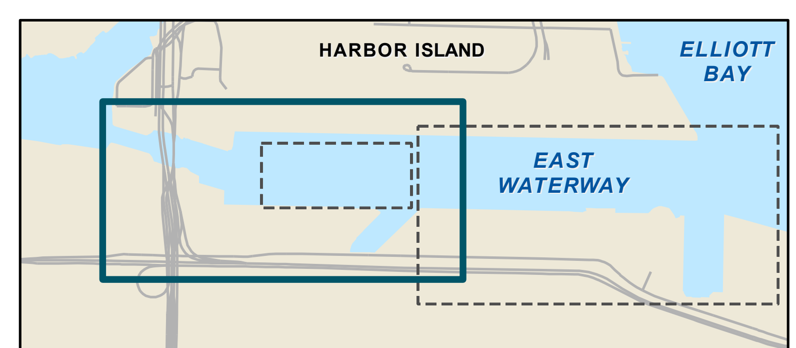
Technology Assignments

- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- Partial Removal and ENR-nav
- ENR-sill
- ENR-nav
- Underpier: 1A(12): MNR; 1B(12): In Situ Treatment; 1C+(12): Hydraulic Dredging Followed by In Situ Treatment
- Underpier: 1A (12): MNR; 1B(12) and 1C+(12): In Situ Treatment
- Under Low Bridge: 1A(12): MNR; 1B(12) and 1C+(12): ENR-sill
- Riprap (No Action)
- No Action

Exceedance Status

- ≤ RAL(12) and ≤ SQS
- > RAL(12) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

CMA Boundaries



0 150 300 450 600

Scale in Feet

Figure 2a

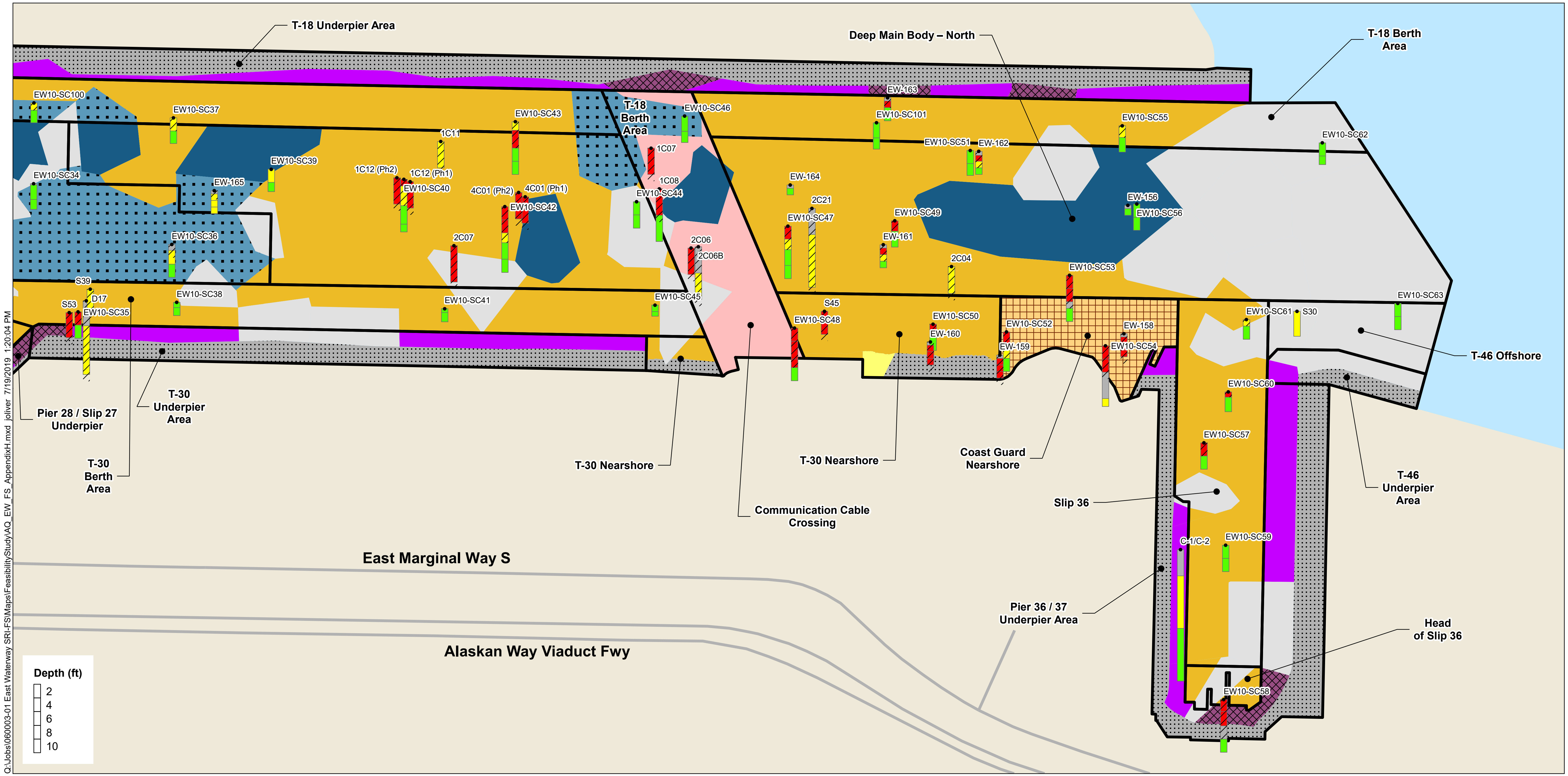
Subsurface Contamination Remaining

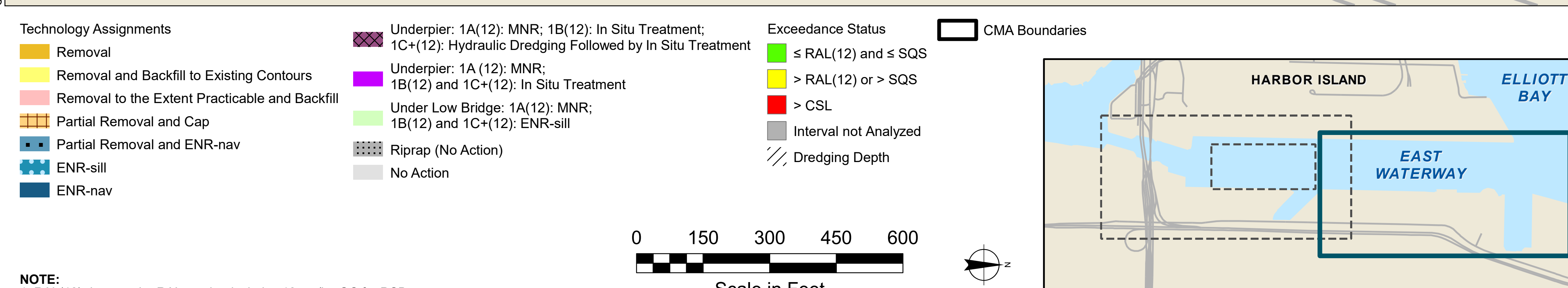
Alternatives 1A(12), 1B(12), 1C+(12) - South

Feasibility Study - Appendix H

East Waterway Study Area

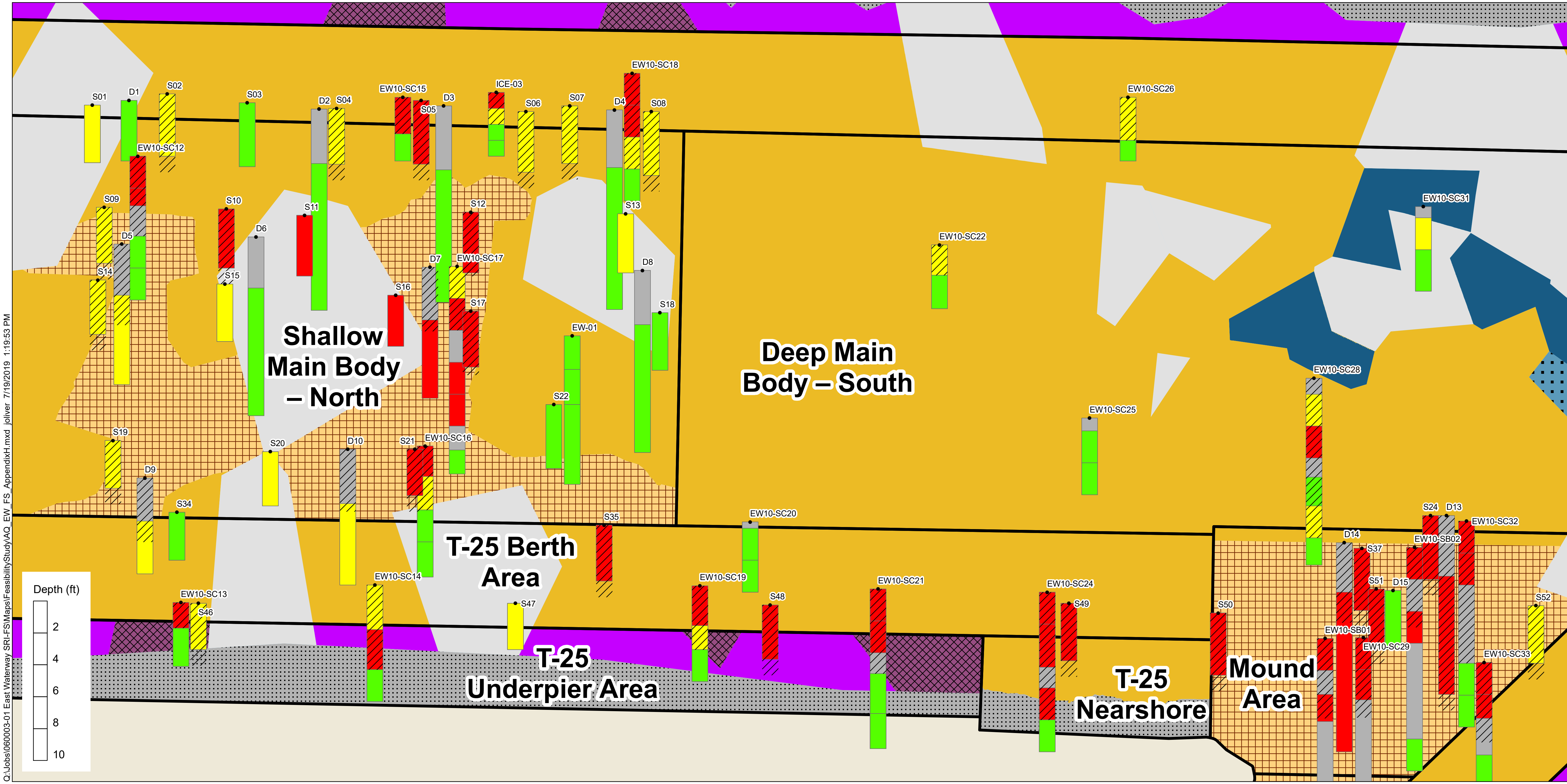
NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs





NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs

Figure 2b
Subsurface Contamination Remaining
Alternatives 1A(12), 1B(12), 1C+(12) - North
Feasibility Study - Appendix H
East Waterway Study Area



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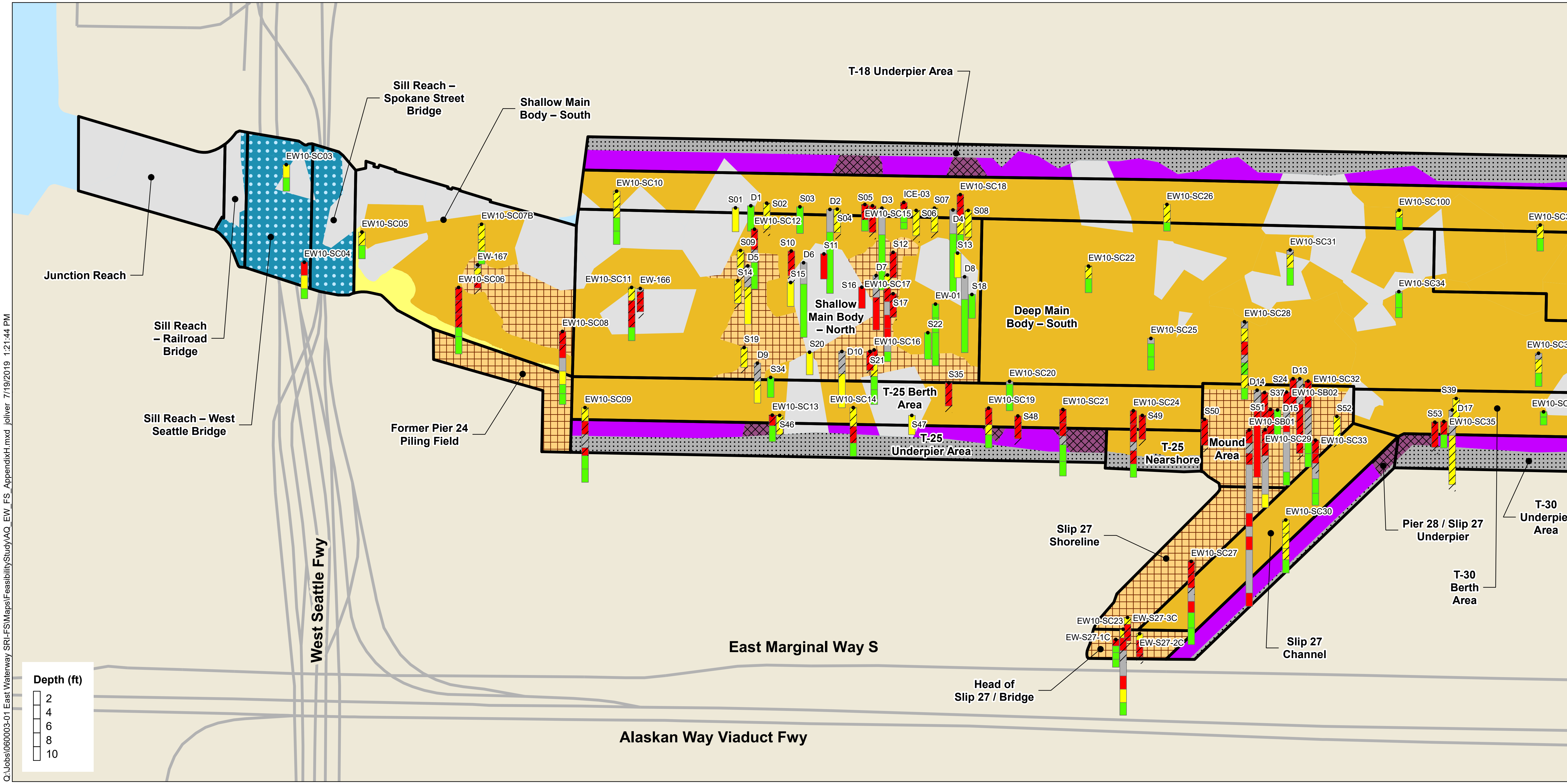
Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- Partial Removal and ENR-nav
- ENR-sill
- ENR-nav
- Underpier: 1A(12): MNR; 1B(12): In Situ Treatment; 1C+(12): Hydraulic Dredging Followed by In Situ Treatment
- Underpier: 1A (12): MNR; 1B(12) and 1C+(12): In Situ Treatment
- Under Low Bridge: 1A(12): MNR; 1B(12) and 1C+(12): ENR-sill
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(12) and ≤ SQS
- > RAL(12) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

CMA Boundaries

NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs

Figure 2c
Subsurface Contamination Remaining
Alternatives 1A(12), 1B(12), 1C+(12) - Detail, South
Feasibility Study - Appendix H
East Waterway Study Area



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Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: 2B(12): In Situ Treatment; 2C+(12): Hydraulic Dredging Followed by In Situ Treatment
- Underpier: In Situ Treatment
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(12) and ≤ SQS
- > RAL(12) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

CMA Boundaries

NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs

0 150 300 450 600
Scale in Feet

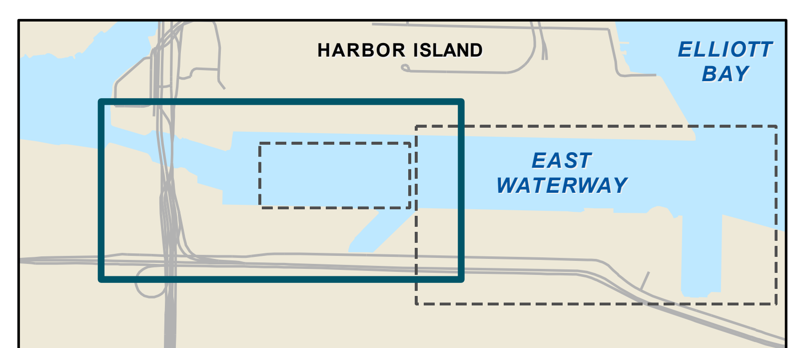
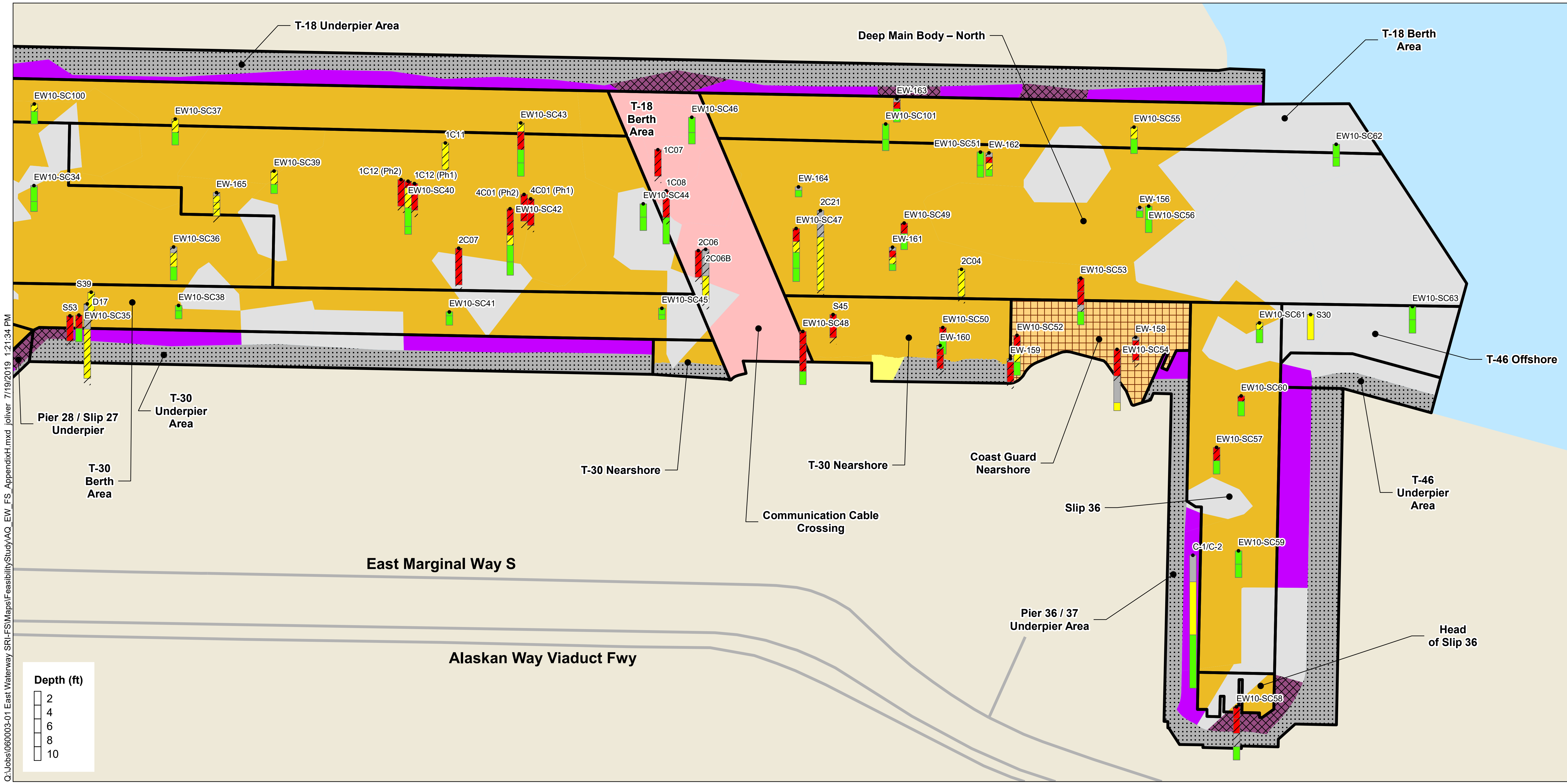


Figure 3a
Subsurface Contamination Remaining
Alternatives 2B(12), 2C+(12) - South
Feasibility Study - Appendix H
East Waterway Study Area



Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: 2B(12): In Situ Treatment; 2C+(12): Hydraulic Dredging Followed by In Situ Treatment
- Underpier: In Situ Treatment
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(12) and ≤ SQS
- > RAL(12) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

CMA Boundaries

NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs

0 150 300 450 600

Scale in Feet

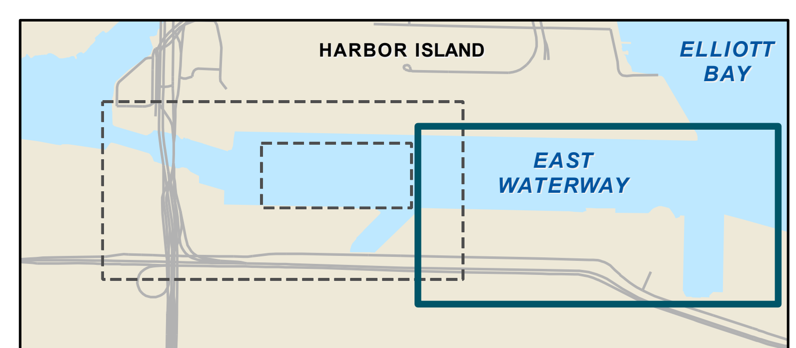
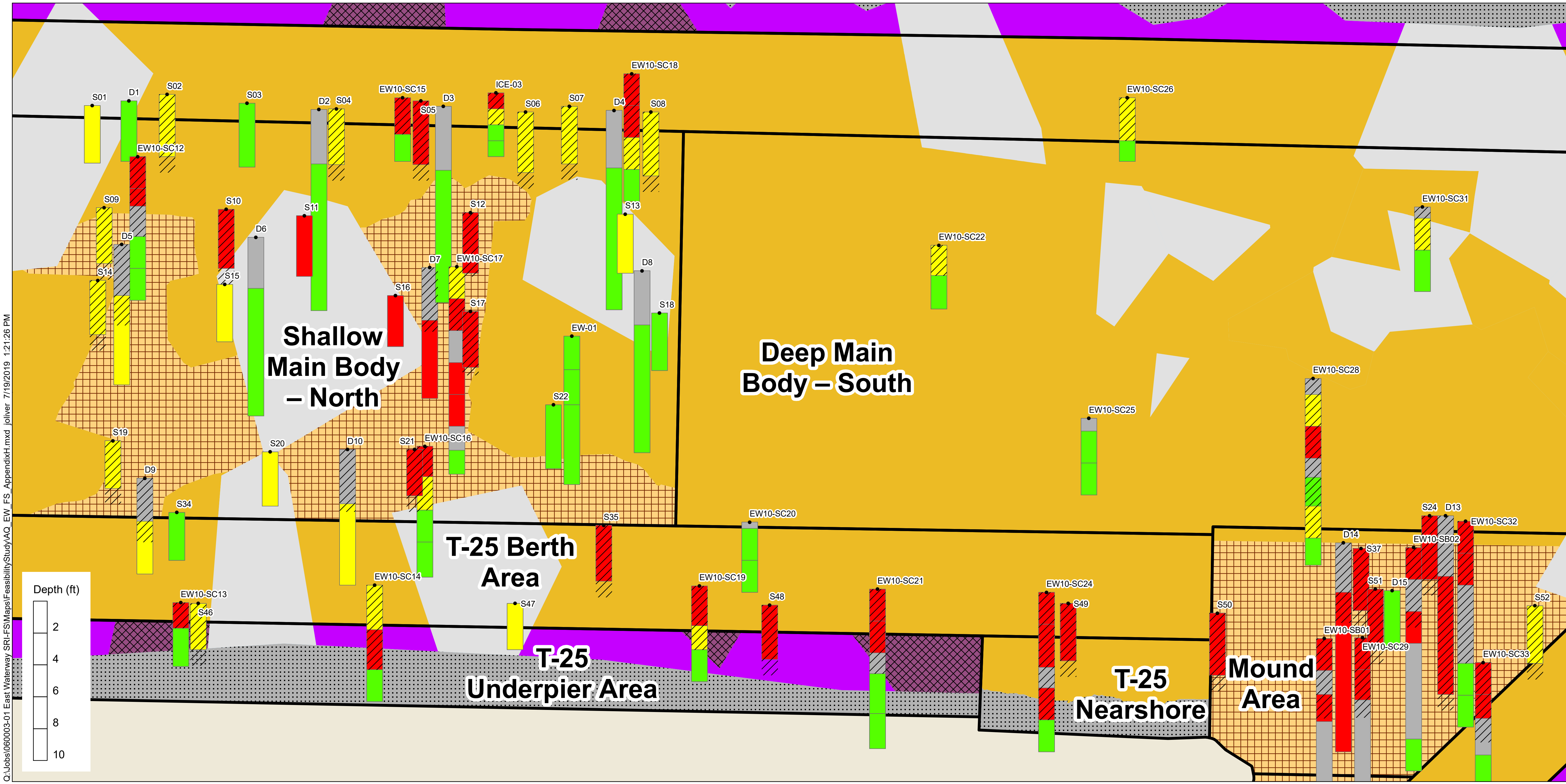


Figure 3b
Subsurface Contamination Remaining
Alternatives 2B(12), 2C+(12) - North
Feasibility Study - Appendix H
East Waterway Study Area



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Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: 2B(12): In Situ Treatment; 2C+(12): Hydraulic Dredging Followed by In Situ Treatment
- Underpier: In Situ Treatment
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(12) and ≤ SQS
- > RAL(12) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

CMA Boundaries

NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs

0 60 120 180 240
Scale in Feet

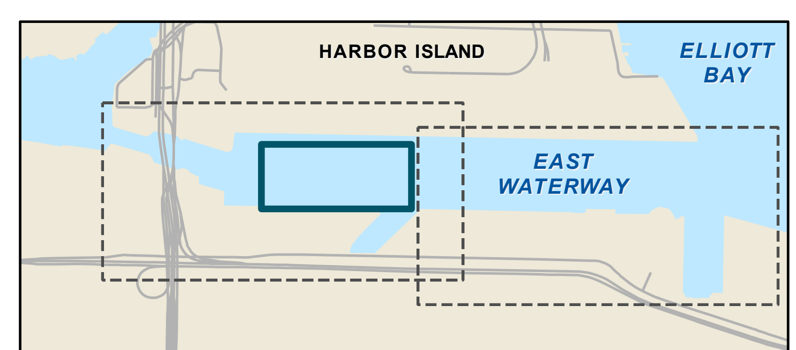
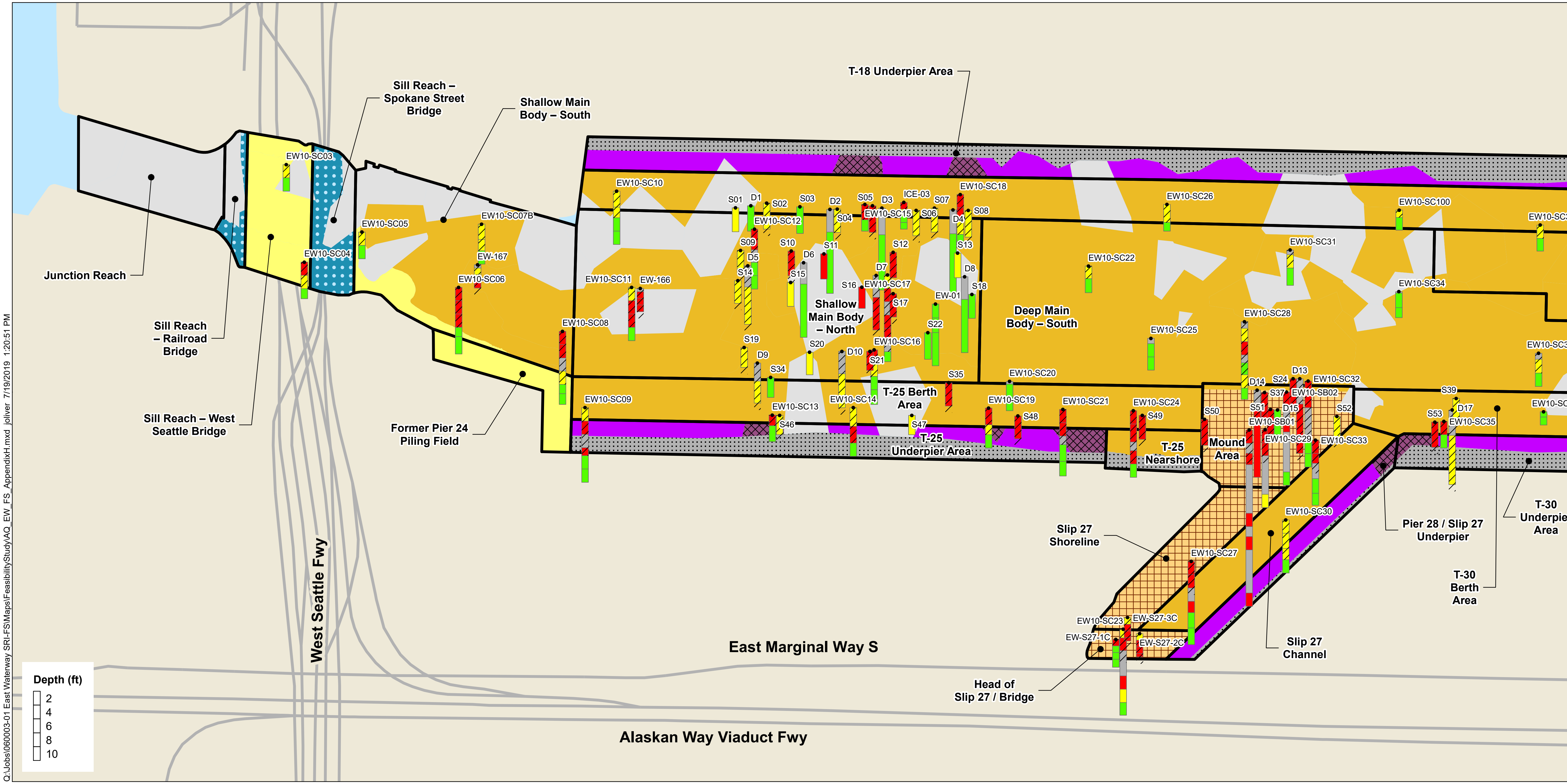


Figure 3c
Subsurface Contamination Remaining
Alternatives 2B(12), 2C+(12) - Detail, South
Feasibility Study - Appendix H
East Waterway Study Area



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Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: 3B(12): In Situ Treatment; 3C+(12): Hydraulic Dredging Followed by In Situ Treatment
- Underpier: In Situ Treatment
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(12) and ≤ SQS
- > RAL(12) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

CMA Boundaries

NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs

0 150 300 450 600
Scale in Feet

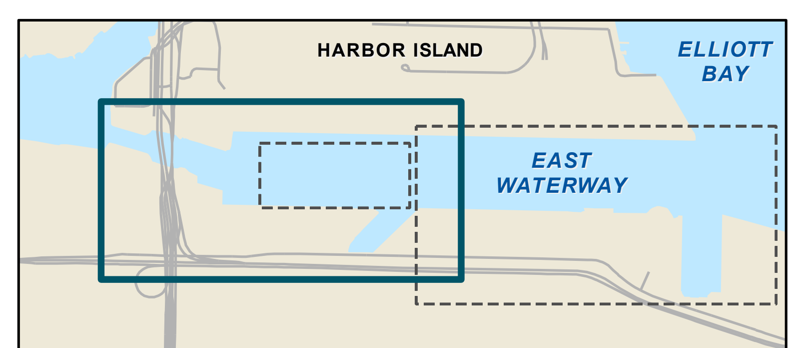
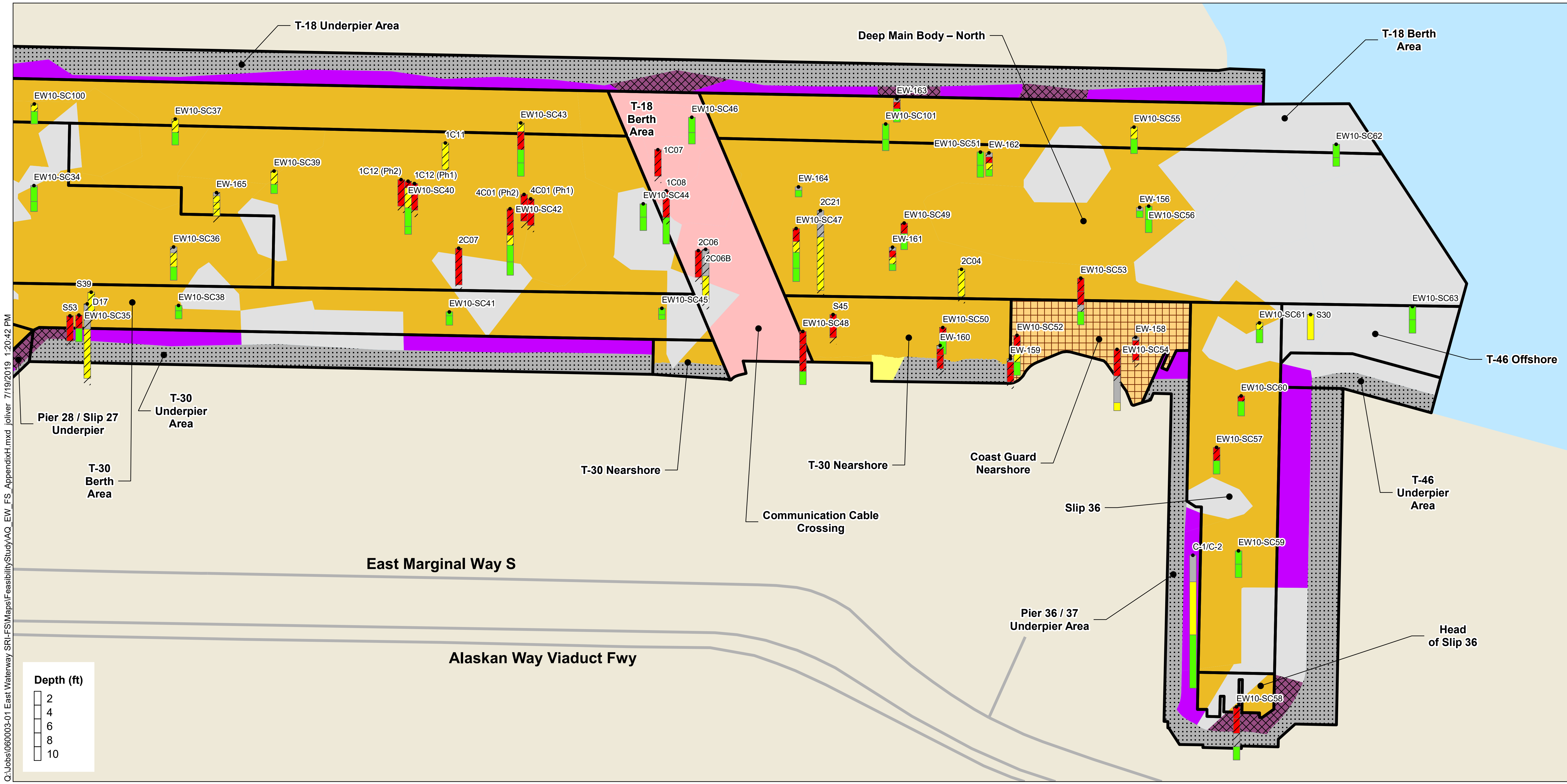


Figure 4a
Subsurface Contamination Remaining
Alternatives 3B(12), 3C+(12) - South
Feasibility Study - Appendix H
East Waterway Study Area

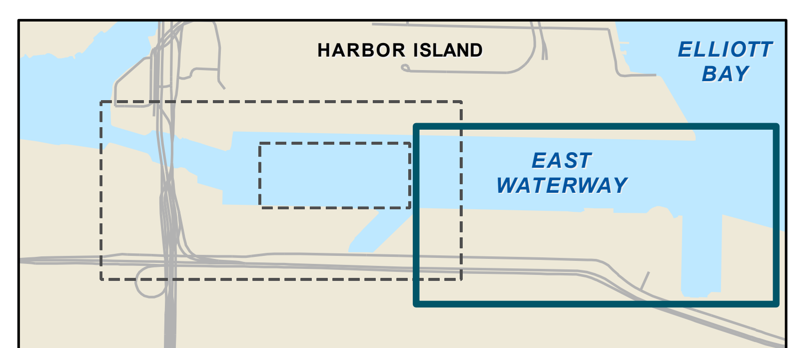


Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: 3B(12): In Situ Treatment; 3C+(12): Hydraulic Dredging Followed by In Situ Treatment
- Underpier: In Situ Treatment
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(12) and ≤ SQS
- > RAL(12) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

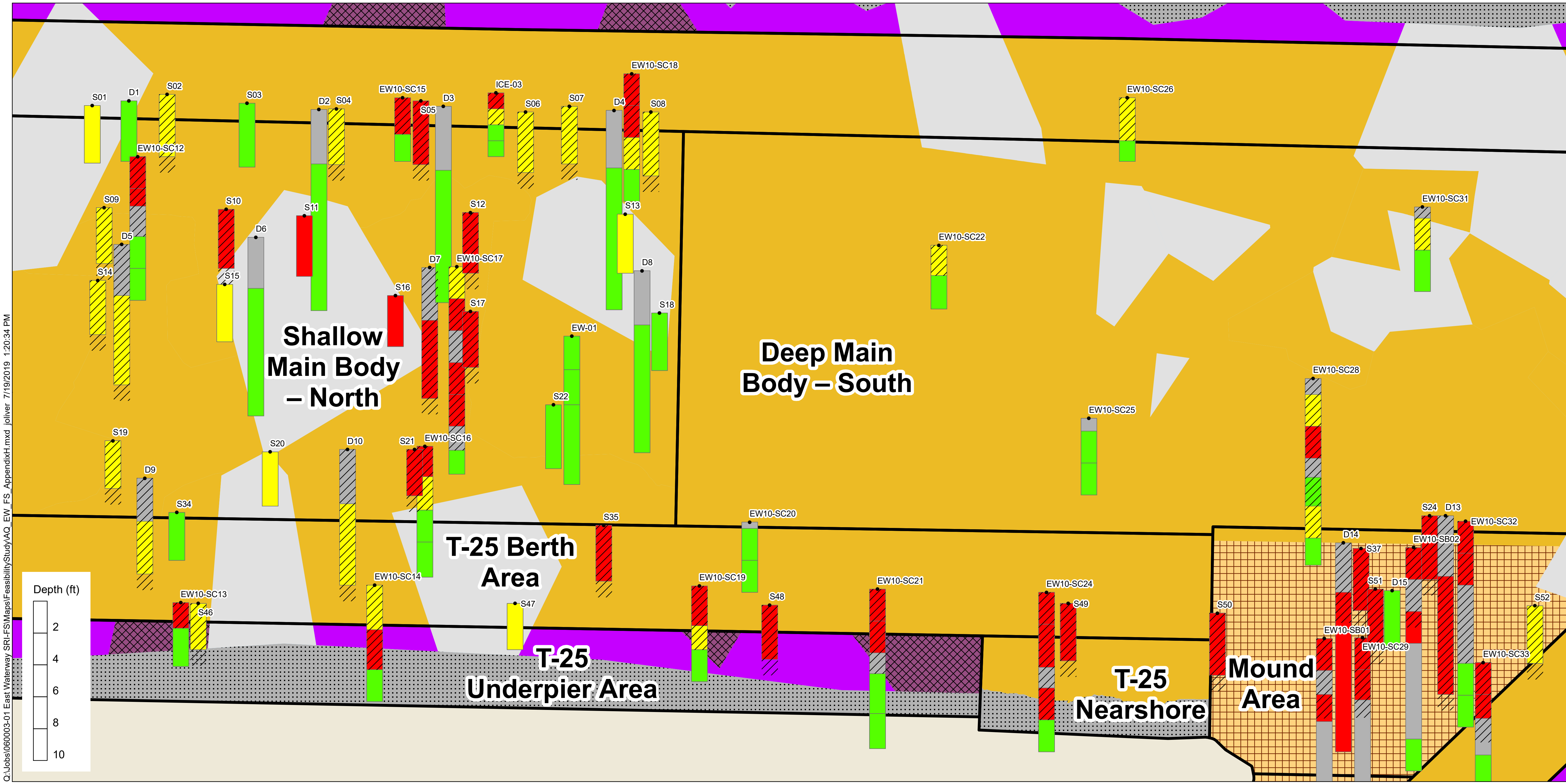
CMA Boundaries

0 150 300 450 600
Scale in Feet



NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs

Figure 4b
Subsurface Contamination Remaining
Alternatives 3B(12), 3C+(12) - North
Feasibility Study - Appendix H
East Waterway Study Area



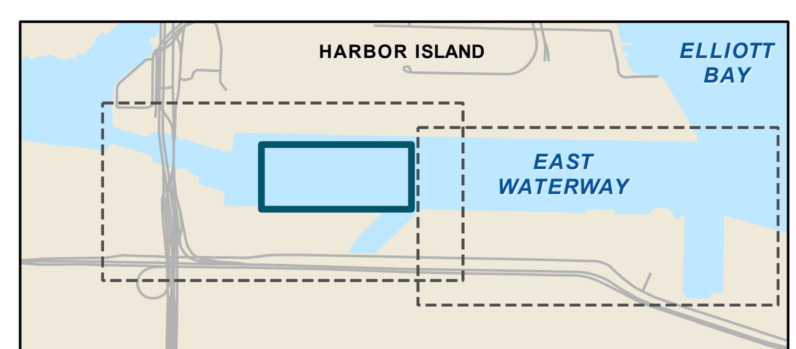
Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: 3B(12): In Situ Treatment; 3C+(12): Hydraulic Dredging Followed by In Situ Treatment
- Underpier: In Situ Treatment
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(12) and ≤ SQS
- > RAL(12) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

CMA Boundaries

0 60 120 180 240

Scale in Feet



NOTE:
1. RAL(12) denotes the RAL set that includes 12 mg/kg-OC for PCBs

Figure 4c
Subsurface Contamination Remaining
Alternatives 3B(12), 3C+(12) - Detail, South
Feasibility Study - Appendix H
East Waterway Study Area

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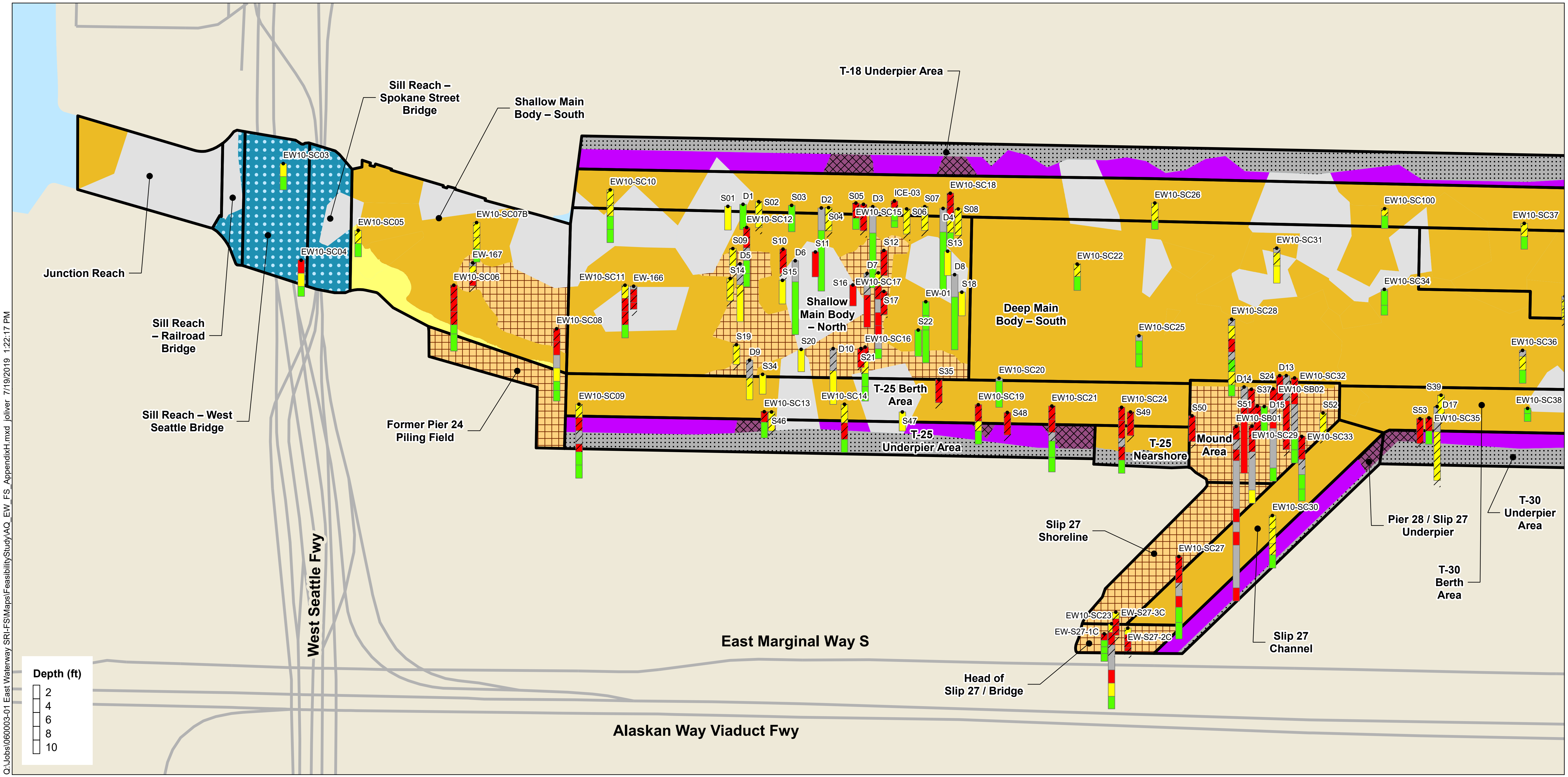
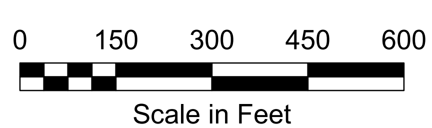


Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: Hydraulic Dredging Followed by In Situ Treatment
- Underpier: In Situ Treatment
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(7.5) and ≤ SQS
- > RAL(7.5) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

CMA Boundaries

NOTE:
1. RAL(7.5) denotes the RAL set that includes 7.5 mg/kg-OC for PCBs



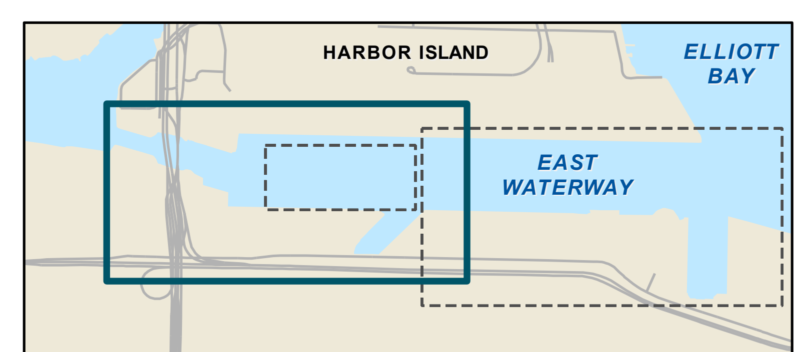
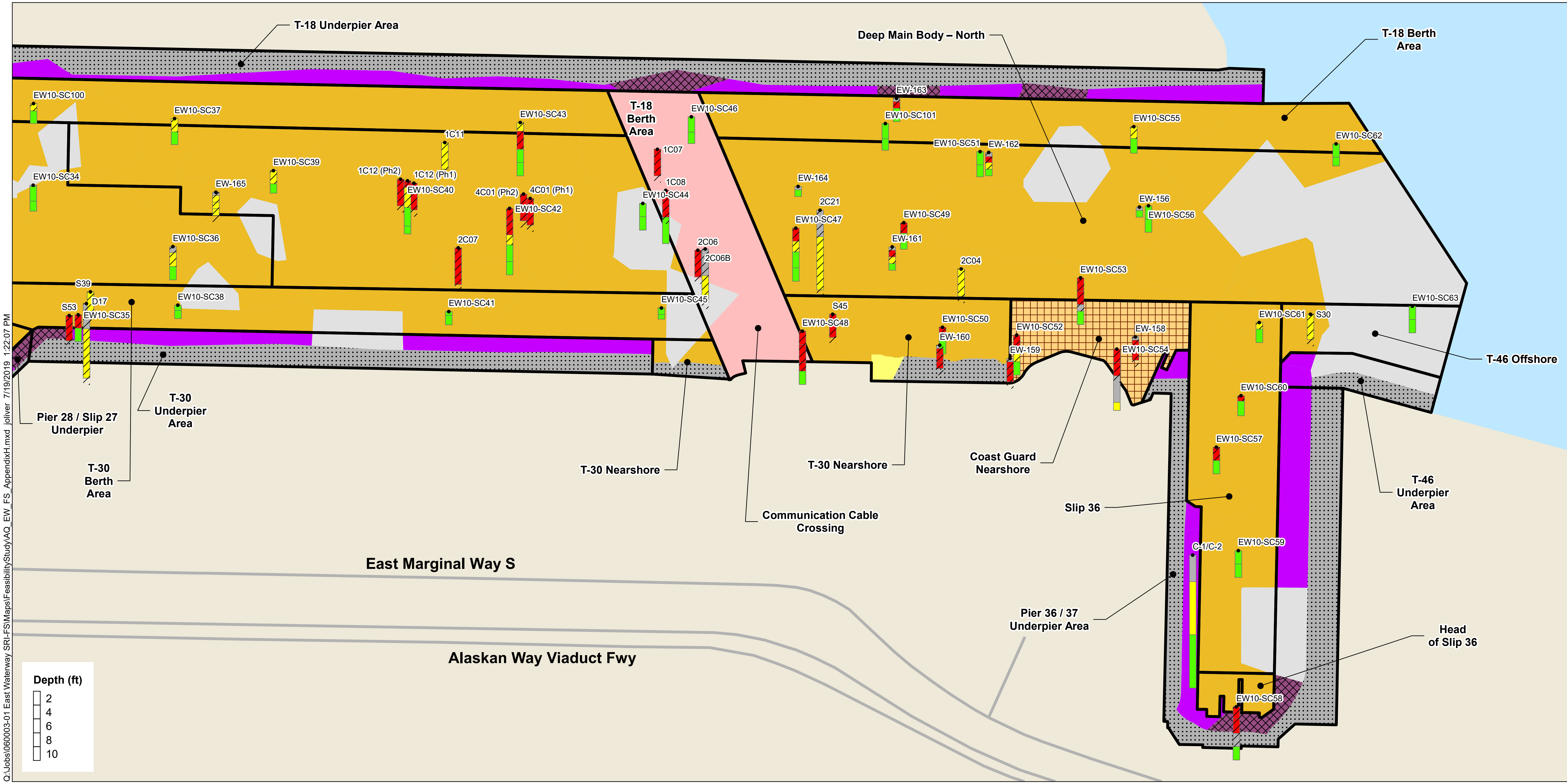


Figure 5a
Subsurface Contamination Remaining
Alternative 2C+(7.5) - South
Feasibility Study - Appendix H
East Waterway Study Area



Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: Hydraulic Dredging Followed by In Situ Treatment
- Underpier: In Situ Treatment
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(7.5) and ≤ SQS
- > RAL(7.5) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

CMA Boundaries

NOTE:
1. RAL(7.5) denotes the RAL set that includes 7.5 mg/kg-OC for PCBs

0 150 300 450 600

Scale in Feet

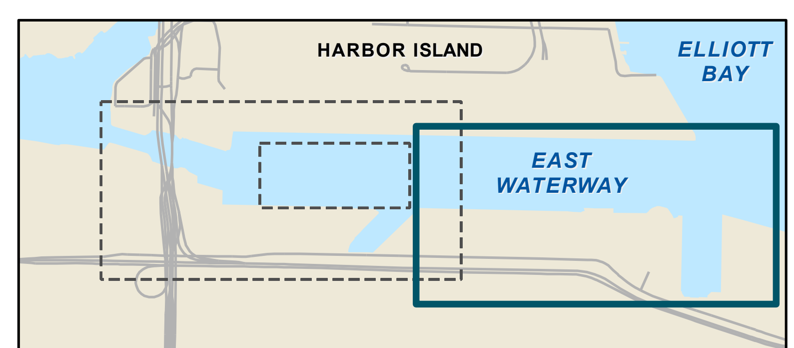
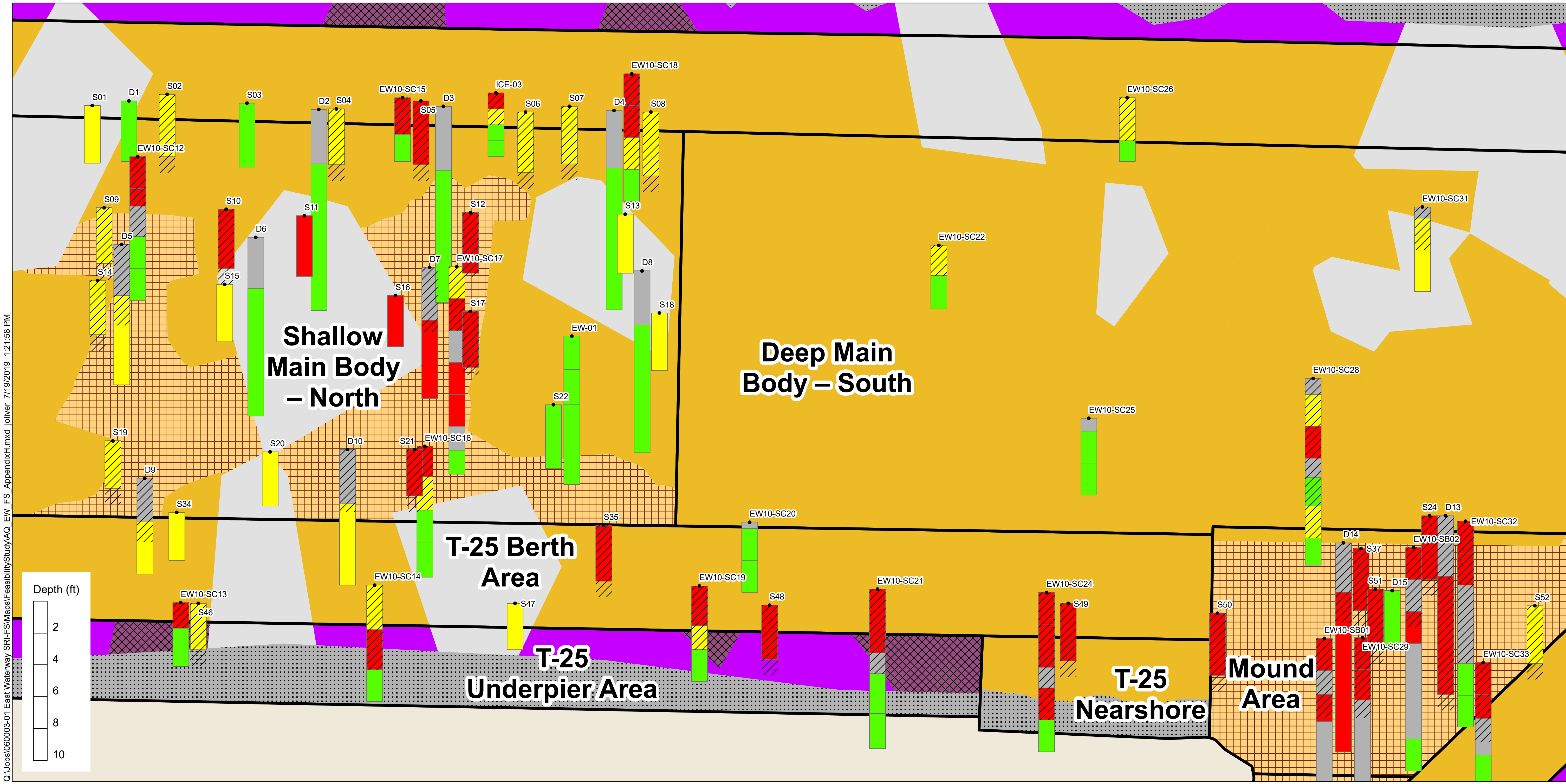


Figure 5b
Subsurface Contamination Remaining
Alternative 2C+(7.5) - North
Feasibility Study - Appendix H
East Waterway Study Area

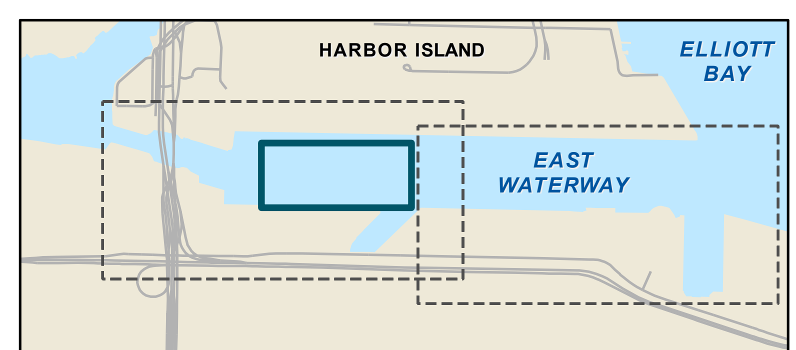


Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: Hydraulic Dredging Followed by In Situ Treatment
- Underpier: In Situ Treatment
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(7.5) and ≤ SQS
- > RAL(7.5) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

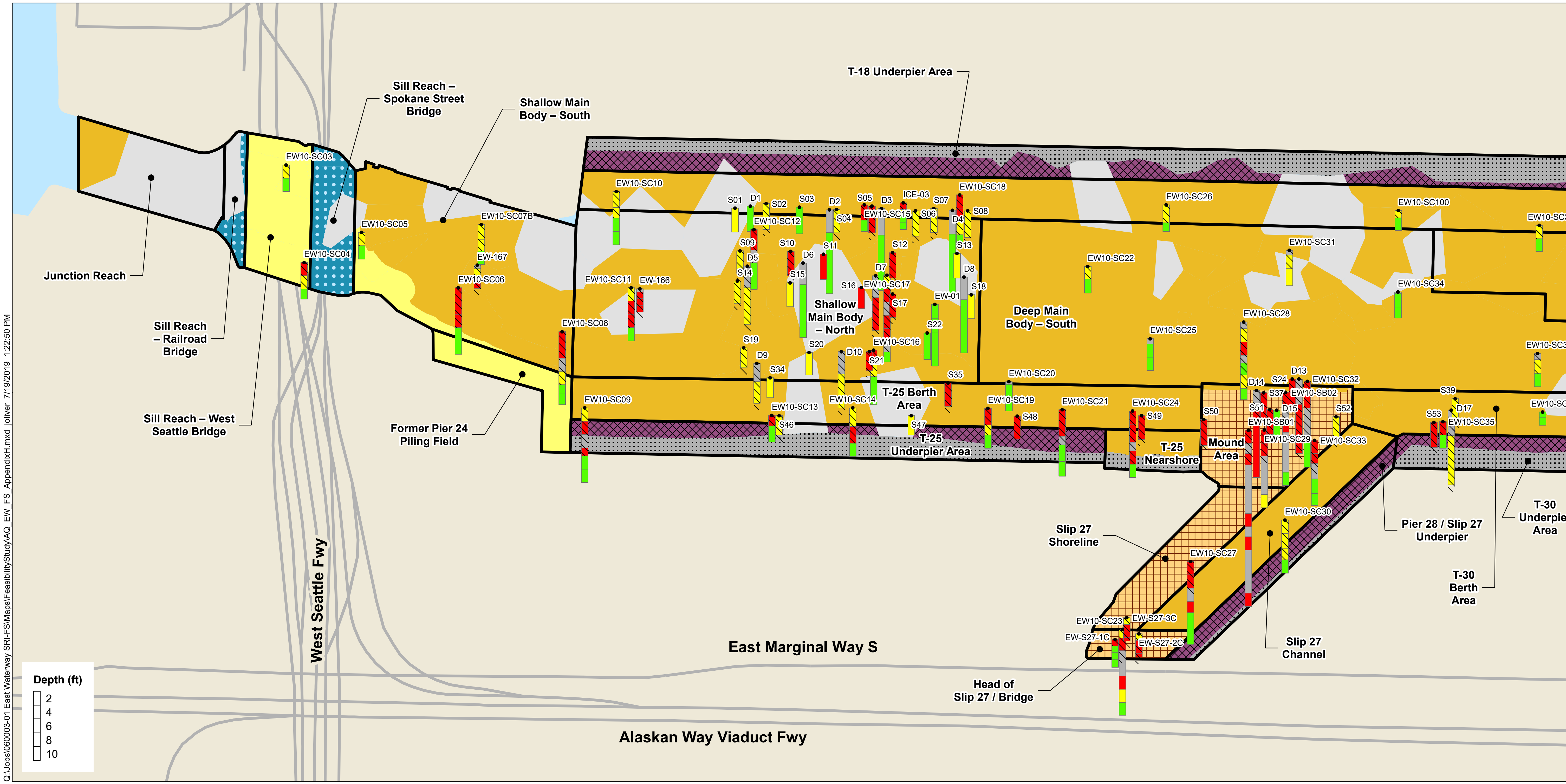
CMA Boundaries

0 60 120 180 240
Scale in Feet



NOTE:
1. RAL(7.5) denotes the RAL set that includes 7.5 mg/kg-OC for PCBs

Figure 5c
Subsurface Contamination Remaining
Alternative 2C+(7.5) - Detail, South
Feasibility Study - Appendix H
East Waterway Study Area



Technology Assignments

- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: Hydraulic Dredging Followed by In Situ Treatment
- Riprap (No Action)
- No Action

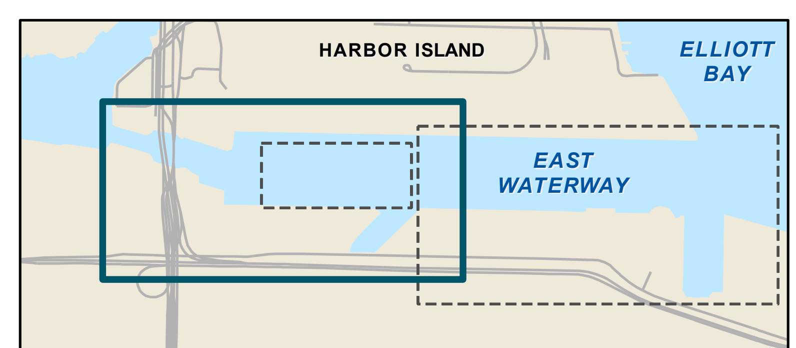
Exceedance Status

- ≤ RAL(7.5) and ≤ SQS
- > RAL(7.5) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

CMA Boundaries

0 150 300 450 600

Scale in Feet



NOTE:
1. RAL(7.5) denotes the RAL set that includes 7.5 mg/kg-OC for PCBs

Figure 6a
Subsurface Contamination Remaining
Alternative 3E(7.5) - South
Feasibility Study - Appendix H
East Waterway Study Area

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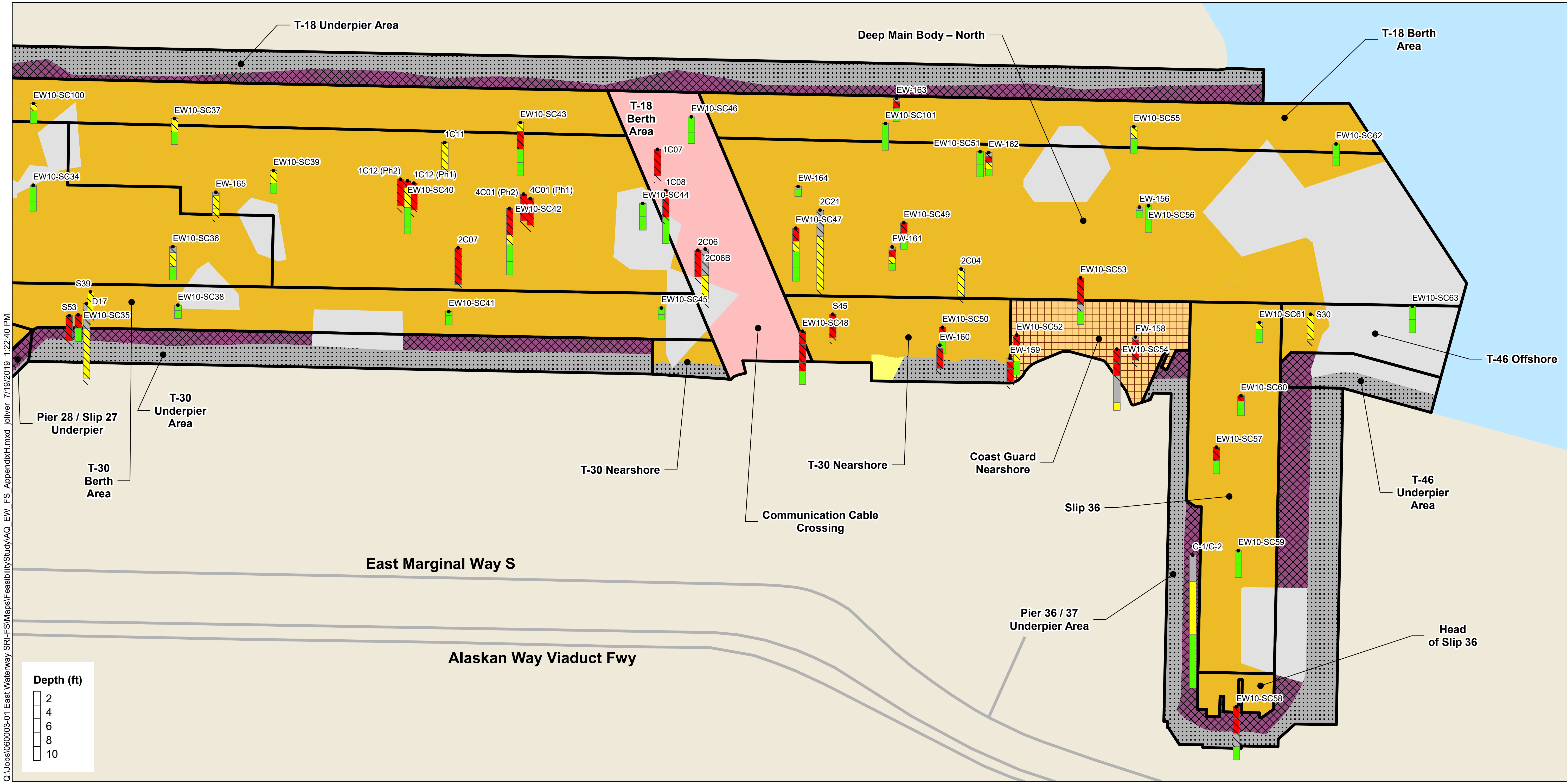

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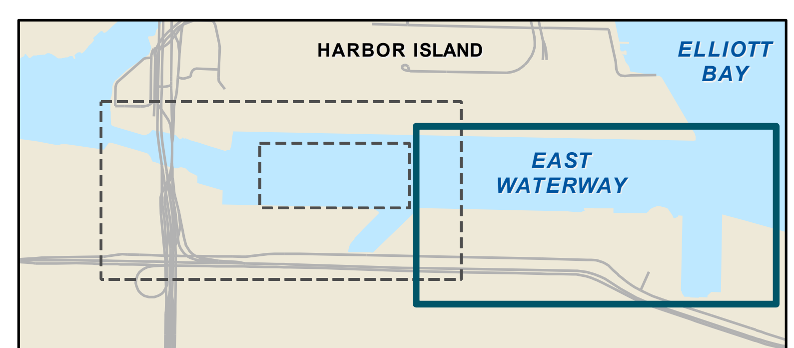
Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: Hydraulic Dredging Followed by In Situ Treatment
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(7.5) and ≤ SQS
- > RAL(7.5) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

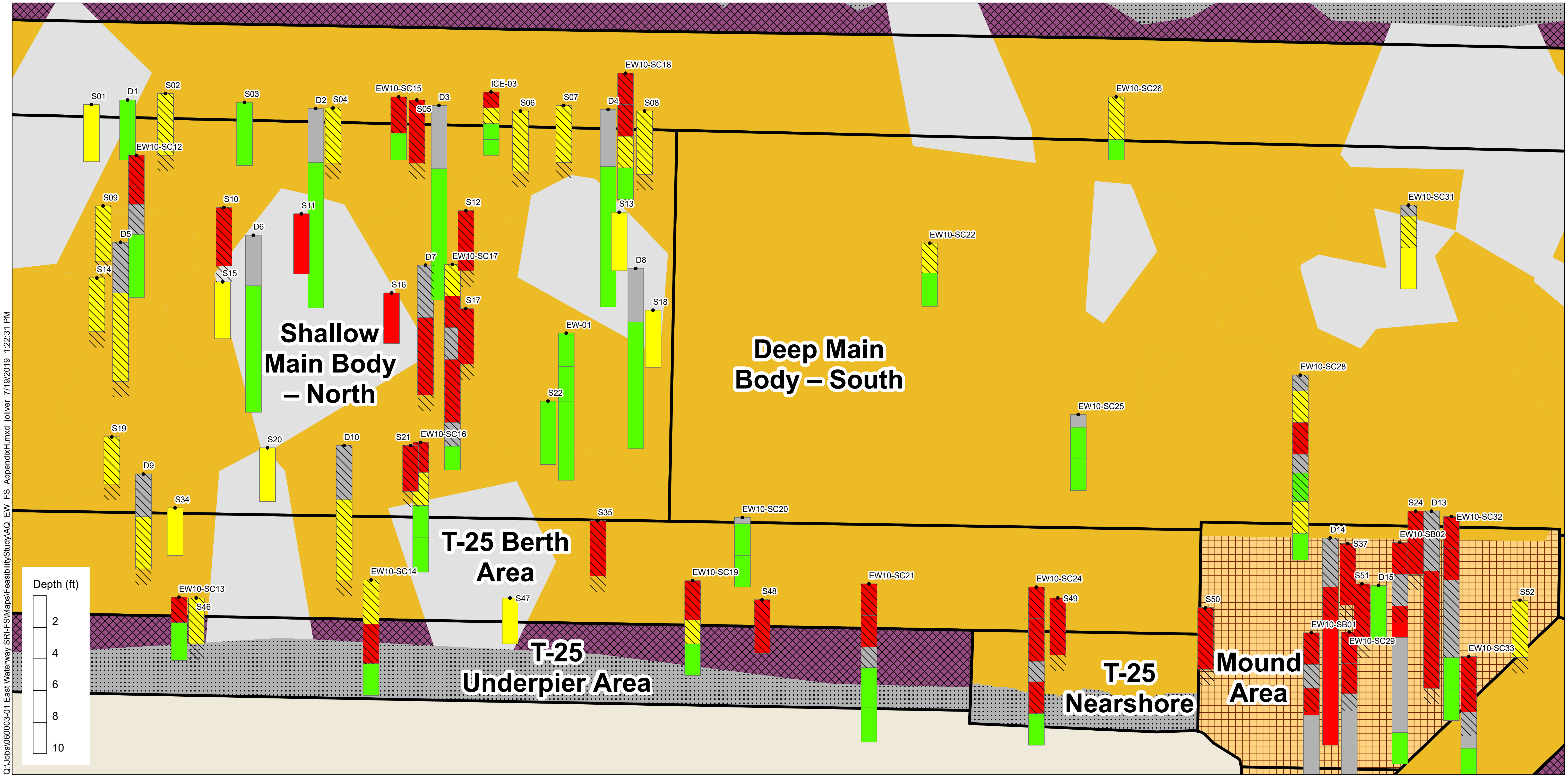
CMA Boundaries

0 150 300 450 600
Scale in Feet



NOTE:
1. RAL(7.5) denotes the RAL set that includes 7.5 mg/kg-OC for PCBs

Figure 6b
Subsurface Contamination Remaining
Alternative 3E(7.5) - North
Feasibility Study - Appendix H
East Waterway Study Area



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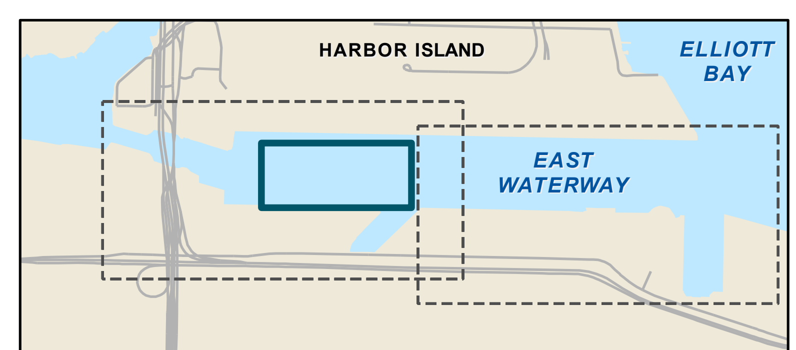
Technology Assignments
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- ENR-sill
- Underpier: Hydraulic Dredging Followed by In Situ Treatment
- Riprap (No Action)
- No Action

Exceedance Status
- ≤ RAL(7.5) and ≤ SQS
- > RAL(7.5) or > SQS
- > CSL
- Interval not Analyzed
- Dredging Depth

CMA Boundaries

0 60 120 180 240
Scale in Feet



NOTE:
1. RAL(7.5) denotes the RAL set that includes 7.5 mg/kg-OC for PCBs

Figure 6c
Subsurface Contamination Remaining
Alternative 3E(7.5) - Detail, South
Feasibility Study - Appendix H
East Waterway Study Area

APPENDIX I – SHORT-TERM EFFECTIVENESS METRICS

EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

Prepared for

Port of Seattle

Prepared by

Anchor QEA, LLC

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Seattle, Washington 98101

June 2019

APPENDIX I TABLE OF CONTENTS

PART 1: AIR EMISSIONS INVENTORY

TABLE OF CONTENTS

List of Tables

1 INTRODUCTION

An air emissions inventory has been conducted in this appendix as one of the measures of short-term effectiveness used for the CERCLA evaluation of alternatives for Sections 9 and 10 of the East Waterway (EW) Feasibility Study (FS). The main objective of this assessment was to estimate and compare the air pollutant emissions expected to result from the implementation of each alternative and includes the following primary components:

- The identification of the major activities associated with the implementation of the alternatives (primarily associated with the combustion of diesel fuel), which result in air pollutant emissions.
- The inventory of air pollutant emissions estimated from these activities over the likely period of time determined for implementation to occur.

This emissions inventory has generally been conducted in accordance with widely-accepted international (WRI/WBCSD 2004) and national (EPA 2005) greenhouse gas (GHG) accounting protocols and guidance. A GHG inventory is a quantification of GHGs emitted to or removed from the atmosphere during a specific period of time associated with a process or project (EPA 2017a). The net carbon emission or sequestration associated with a defined activity is often referred to as the activity's carbon footprint. This inventory considers one GHG (which would contribute to the project's carbon footprint) and seven exhaust air pollutants. In addition to carbon dioxide (CO_2) (the GHG), emissions were estimated for the following air pollutants (which are not GHGs) as part of this inventory:

- Nitrogen oxides (NO_X)
- Sulfur dioxide (SO_2)
- Carbon monoxide (CO)
- Volatile organic compounds (VOCs)
- Hydrocarbons (HC)
- Particulate matter less than 10 microns in diameter (PM_{10})
- Particulate matter less than 2.5 microns in diameter ($PM_{2.5}$)

2 OPERATIONAL BOUNDARIES AND SOURCES

The emissions accounting protocols (WRI/WBCSD 2004; EPA 2005) specify establishing "operational boundaries" for the emissions-generating entity under consideration (referred to as the 'reporting entity,' which can be a country, company, or project). This process involves identifying emissions sources associated with its "operations" (in this case the anticipated activities associated with the implementation of each alternative), and categorizing the resultant emissions as Scope 1 ("direct"), Scope 2 ("indirect"), or Scope 3 ("optional"), which are defined in the subsections below (WRI/WBCSD 2004; EPA 2005[1]).

2.1 Emissions Categories and Sources

2.1.1 Scope 1: Direct Emissions

Scope 1 (direct) emissions are from sources derived from conducting remedial activities and owned or controlled by the reporting entity, (e.g., stationary, mobile, and process-related sources from owned or controlled construction equipment and vehicles).

The following construction activities identified as contributing to direct emissions from diesel fuel combustion were accounted for within the operational boundaries considered in this inventory:

- Site Preparation
  - Equipment mobilization and demobilization
  - Pile removal
- Sediment Removal
  - Open-water dredging (mechanical)
  - Restricted access dredging (under the West Seattle Bridge)
  - Diver-assisted hydraulic dredging (in underpier areas)
  - Sediment pumping (due to hydraulic dredging in underpier areas)
- Sediment Transloading and Disposal

[1] Scope 1, 2, and 3 emissions categories are designations presented in WRI/WBCSD (2004). "Direct," "indirect," and "optional" are associated descriptive terms, as well as corresponding designations presented in EPA (2005).

  - Mechanical offloading, which includes the following:
    - Transportation (via tug and barge) of dredged sediments to an offloading area outside the EW
    - Transportation (via rail) of dredged sediments for landfill disposal in eastern Washington state
- Capping/treatment Material Placement:
  - Transportation of materials to the EW, which includes the following:[2]
    - Transportation (via truck) of capping materials (i.e., sand, gravel, or armor stone) from a quarry to an onshore staging area
    - Transportation (via tug and barge) of capping materials from a staging area to the EW
    - Transportation (via rail) of in situ treatment material (activated carbon) from a vendor to the EW
  - Placement of sand for residuals management cover, capping, backfill, and enhanced natural recovery (ENR)
  - Placement of gravel for capping
  - Placement of armor stone for capping
  - Placement of activated carbon for in situ treatment (in underpier areas)
  - Placement of sand for ENR (under low bridges)
- Long-term Monitoring

This inventory estimates engine emissions from construction equipment and vehicles anticipated to be used to implement the activities listed above and during the time period in which each alternative is expected to be implemented. While these activities are not meant to be all-inclusive, they are likely to contribute the majority of emissions associated with the implementation of the alternatives. Emissions were generally estimated for these activities based on assumptions associated with the type and number of equipment and vehicles, the duration of their use based on the specific activities, the effective operation time, and the

[2] See Section 2.1.3 for the basis for inclusion of these activities in Scope 1 (direct) emissions, rather than Scope 3 (optional) emissions.

daily fuel consumption. Because no alternative fuels were specifically identified as a fuel source during the development of alternatives in Section 8 of the FS, this inventory was based entirely on tracking fossil fuel consumption (primarily diesel fuel[3]). However, the opportunities for renewable energy source use in remedial action construction are identified in Part 2 of this appendix, and as discussed therein, could be evaluated and implemented where feasible during remedial design to help reduce the emissions associated with the selected alternative.

2.1.2 Scope 2: Indirect Emissions

Scope 2 (indirect) emissions are a consequence of conducting remedial activities of the reporting entity, but occur at sources owned or controlled by another entity and specifically result from the import or purchase of electricity, heating/cooling, or steam, and related transmission and distribution.

Indirect emissions were estimated in this inventory for the electricity used at the water treatment facility, where hydraulically dredged materials from underpier areas are handled and processed (i.e., treatment of dewatered liquid and contaminants). Other indirect emissions resulting from electricity usage associated with any ancillary activities (e.g., field trailer operations) were not included in this inventory because specific details related to these activities would not be available until remedial design.

2.1.3 Scope 3: Other Indirect Emissions (Optional)

Scope 3 (other indirect) emissions are typically considered optional in terms of reporting (WRI/WBCSD 2004; EPA 2005). These would be emissions that are a consequence of the activities of the reporting entity, but occur from sources not owned or controlled by that entity (and are not part of that entity's direct or indirect emissions). Examples of Scope 3 emission sources might include extraction and production of purchased materials; extraction, production, and transportation of purchased fuels; use of sold products; or employee commuting.

[3] For the purposes of this FS, sulfur content of diesel fuel is assumed to be 15 ppm (ultra-low sulfur diesel).

Emissions of this type have not been included because they were considered beyond the scope of this analysis, and it is unknown to what extent they would be accounted for in any inventories conducted by source entities (i.e., vendors, contractors, etc.).
Another source of emissions often considered as Scope 3 or "optional" is the transportation of purchased materials and waste disposal. While transportation of placement materials (for capping and treatment) and dredged sediments to and from the EW may fall under the control of a contracted entity, the emissions resulting from these activities are of significant magnitude relative to the other direct emissions from dredging activities[4]. Therefore, these emissions are included in this inventory in the direct emissions category because transportation of both capping (via truck and tug/barge) and treatment materials (via rail), and disposal of dredged sediment (via tug/barge and rail) are significant components of the remedial activities.

2.2 Emissions Not Included in This Inventory

The goal of this assessment is to account for the activities expected to contribute the majority of emissions associated with implementation of the alternatives. This approach is appropriate considering the FS-level analysis of alternatives presented in this document. While the major components of each alternative have been generally well defined in Section 8 of the FS, more detailed information pertaining to specific remedial activities will not be developed for the selected alternative until the design stage. Therefore, the activities discussed in the following subsections were considered in the analysis, but were not included in this inventory due to a lack of a basis for estimation at this time (or for other reasons as noted).

2.2.1 Scope 1: Direct Emissions

- Staging area and access road construction activities
- Transloading facility development (i.e., an onshore facility where dredged material would be stockpiled, dewatered, and loaded by rail for upland disposal)
- Any emissions at the Subtitle D landfill related to handling of sediments for disposal

[4] EPA (2005, pages 20 and 21) identifies situations in which "optional" emission activities may be included in the direct emissions category. The discussion in item 2 on page 21 specifically pertains to considering the relevance of the optional emission categories.

2.2.2 Scope 2: Indirect Emissions

- Electricity consumption likely to occur during implementation of an alternative, for example:
  - Indirect emissions from purchased electricity to power field office trailers or similar facilities
  - Heating or cooling energy requirements for any of the above facilities

2.2.3 Scope 3: Other Indirect Emissions (Optional)

- As noted in Section 2.1.3, optional emissions resulting from activities related to the processing of materials that will be used as part of the remediation (e.g., quarrying of riprap [armor stone], refining of diesel fuel, and excavation of gravel or sand from borrow pits) have not been included in this inventory because they were considered beyond the scope of this analysis, and it is unknown to what extent they would be accounted for in any inventories conducted by source entities (i.e., vendors, contractors, etc.).
- Any emissions resulting from employee commuting.

2.2.4 Other Greenhouse Gas Emission Contributions

Total GHG emissions are typically reported as metric tons (tonnes) of carbon dioxide equivalents (CO_2-eq), calculated by multiplying the tonnes of each GHG emitted by that GHG's global warming potential[5] (GWP; EPA 2005) and summing the results. In addition to CO_2, nitrous oxide (N_2O) and methane (CH_4) are other GHGs emitted during diesel fuel combustion (EPA 2008) typically included in the CO_2-eq total. As presented in table A-6 of EPA (2008), for all diesel fuel vehicle types tracked as part of this inventory, emission factors (EFs) are 0.26 grams per gallon (g/gal) for N_2O and 0.8 g/gal (or less) for CH_4, while CO_2 has an EF of 10.21 kilograms per gallon (kg/gal) (EPA 2011a). Although the GWPs of N_2O and

[5] The GWP represents the effect a given GHG has on global warming in the atmosphere relative to one unit of CO_2. GWPs for all of the GHGs are listed in Table 6-3 of EPA (2005).

CH_4 are 310 and 21, respectively[6], the contribution of CO_2 to CO_2-eq is more than 100 times greater than the collective contribution of N_2O and CH_4[7]. For this reason, emissions from N_2O and CH_4 would not be discernible in a CO_2-eq total reported to two significant figures (as is typical engineering practice for this type of evaluation), and have not been included in this inventory due to this *de minimus* contribution. Therefore, CO_2 and CO_2-eq should be considered equivalent in this inventory.

[6] For every tonne of GHG emitted, the contribution to global warming associated with N_2O and CH_4 are 310 and 21 times higher, respectively, than for CO_2.

[7] For each gallon of diesel fuel burned, the CO_2 contribution over the combined N_2O and CH_4 contribution is equal to 10,210 g CO_2 / [(0.26 g N_2O x 310) + (0.8g CH_4 x 21)] = 104.

3 METHODOLOGY

The alternative cost estimates developed in Appendix E of the FS were used as the primary basis for calculating emissions for each alternative. Specific types and number of construction vehicles and equipment, mass of dredged sediment and mass/volume of placement materials, and production rates for each activity were derived from that appendix.

For the direct emissions category, diesel fuel usage estimates were derived for each activity and alternative on a time basis (for construction equipment and vehicles) and on a mass-distance basis (for placement material and dredged sediment transport), and emissions were then calculated using available EFs from various U.S. Environmental Protection Agency (EPA) sources (see Section 3.2).

For the indirect emissions category, emissions expected to result from operation of the water treatment system were calculated (for those alternatives that included a hydraulic dredging component) based on estimated system operation time, an assumed electricity consumption rate, and available EFs (see Section 3.2).

3.1 Emission Calculation Inputs

3.1.1 Direct Emissions

Direct emissions were calculated based on estimating fuel usage associated with the remedial activities described in Section 2.1.1. Table 1 presents the general inputs for direct emission calculations by activity and alternative, including quantities (i.e., dredged sediment and placement material volume) and production rates obtained from Appendix E of the FS, and selected equipment and daily equipment operation rates assumed based on professional judgment and experience from similar projects.

3.1.1.1 Time-based Fuel Usage Estimates

For all direct emissions-generating activities (except for transportation of placement material and dredged sediment), the following input parameters were used to estimate total diesel fuel usage:

- Assumed construction vehicle or equipment types and number

- Estimated daily vehicle operation and uptime (effective operation time)
- Estimated fuel consumption rates
- Total implementation time (defined as total quantity divided by the specific production rate for each activity)

Table 2 presents a list of the assumptions for equipment and vehicles and fuel usage per piece of equipment considered in the direct emissions inventory.

3.1.1.2 Mass-Distance-based Fuel Usage Estimates

For activities related to transportation of placement material and dredged sediments, a mass-distance travelled approach was used to estimate total fuel usage. The mass of placement material and dredged sediments, and the distance travelled during transportation via rail, truck, or barge was accounted for, and available ton-mile[8]-based fuel economy factors (EPA 2011a) were used to calculate total fuel usage[9]. Therefore, input parameters to estimate fuel usage due to transportation of capping material (via truck and tug/barge), activated carbon (via rail), and dredged sediment for disposal (via rail) included the mass of materials (in tons) and distances travelled (in miles). Assumptions related to rail, truck, and barge diesel fuel consumption and transport capacity are presented in Tables 3, 4, and 5.

3.1.2 Indirect Emissions

Indirect emissions are related to the generation of electricity that would be purchased during remedial activities, as described in Section 2.1.2. Table 6 presents the general inputs for indirect emission calculation by alternative for the sediment removal activity, including quantities and production rate obtained from Appendix E of the FS. A water treatment system is anticipated to consume electricity for treating the hydraulically dredged materials from underpier areas (which applies only to Alternatives 1C+(12), 2C+(12), 3C+(12), 2C+(7.5), and 3E(7.5)). The expected total water treatment operation time and an assumed

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[8] A unit of freight transportation is equivalent to a ton of freight moved 1 mile.

[9] This approach (as opposed to calculating fuel usage based on transport time and fuel consumption rates) was corroborated as most appropriate by Vincent Camobreco at EPA (Office of Transportation and Air Quality) (phone conversation between B. Solomon of Anchor QEA and V. Camobreco of EPA, September 26, 2013).

electricity consumption rate of 250 kilowatts (kW) (Table 7) were used to estimate total electricity usage.

3.2 Emission Factor Sources

3.2.1 Direct Emissions

EPA's NONROAD (2017b) and NMIM (2017c) models for estimating emissions from a fleet of construction equipment and vehicles were considered for this inventory. These models allow a user to specify equipment and vehicle type based on pre-defined equipment categories, horsepower, model year, and activity. Upon detailed review of these models, it was noted that available project details at the FS level would not readily align with several required input parameters and, therefore, attempts to accurately assign values to these parameters would introduce a potentially high degree of uncertainty. For example, a major input parameter is equipment and vehicle model years, which will not be known until the design stage for the selected alternative, and cannot accurately be estimated at the FS stage.

Based on correspondence with EPA (2011b), a simpler approach was selected to estimate emissions given the available level of detail regarding equipment and vehicle runtimes, fuel consumption rates, and quantities provided in the cost estimate (Appendix E of the FS). EPA provided a table of air pollutant EFs from the NONROAD model for 2013 (EPA 2013), which contains EFs (in grams of pollutant per gallon of fuel) for various equipment types and horsepower ranges that represent the national average EFs of all equipment and vehicles in use during that year. Finally, the EFs were selected from the 2013 NONROAD table (according to each equipment and vehicle expected to be used during remedial activities) based on horsepower and/or fuel consumption rates, which were determined based on professional judgment and experience on other similar projects. Table 8 presents the EFs for construction equipment and vehicles used in the direct emission inventory.

As described in Section 3.1.1.2, direct emissions associated with the transportation of placement material and dredged sediments were calculated based on tonnage, distance traveled, and diesel fuel economy factors. While national diesel fuel economy and EFs for locomotives were readily available (EPA 2009), such factors for trucks and barges were estimated indirectly by using the CO_2 EF for diesel fuel in kilograms of carbon dioxide per gallon (kg CO_2/gal) (i.e., 10.21 kg CO_2/gal; Table 2 of EPA 2011a) and dividing it by the CO_2 EF specific to trucks and barges in kg CO_2/ton-mile units (Table 9 of EPA 2011a) to derive specific ton-mile/gal fuel economies. The EFs for all air pollutants associated with truck and barge transportation of materials were then selected from the 2013 NONROAD table consistent with the methods described above. Emissions for all placement material and dredged sediment transport activities were based on one-way trips, as the ton-mile-based EFs were calculated from national average freight and fuel totals that were likely to have fuel usage from empty cargo return trips already factored into their values to some degree[10]. Tables 3, 4, and 5 present the EFs specific to rail, truck, and barge transportation of materials used in the direct emission inventory.

3.2.2 Indirect Emissions

The most recent emission rates (2012) for CO_2, NO_X, and SO_2 (in mass per megawatt hour [mass/MWh]) for the Western Electricity Coordinating Council (WECC) Northwest subregion (EPA 2015) were used to calculate indirect emissions from electricity usage for operating a water treatment system associated with the handling of hydraulically dredged materials from underpier areas (Alternatives 1C+(12), 2C+(12), 3C+(12), 2C+(7.5), and 3E(7.5))[11]. Table 7 presents the EFs for electricity consumption used in the indirect emission inventory.

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[10] This information is based on discussion with EPA (see footnote 9).

[11] See Section 2.2.4 regarding N_2O and CH_4. Based on EFs for electricity generation in the WECC Northwest subregion (EPA 2015), the individual contribution of CO_2 to CO_2-eq was calculated to be nearly 200 times greater than the collective contribution of N_2O and CH_4 (i.e., [665.75 lb CO_2/MWh x 1,000 MWh/GWh] / [(10.38 lb N_2O/GWh x 310) + (12.6 lb CH_4/GWh x 21)] = 191).

4 RESULTS AND DISCUSSION

Results from the air emissions inventory are summarized in Tables 9 through 13. These tables include detailed explanatory notes documenting the assumptions, sources of EFs, and methods of each calculation presented.

Tables 9 and 10 report detailed summaries of the direct and indirect emissions associated with the activities (for each piece of construction equipment and vehicle used) and by alternative. All emissions are presented in metric tons.

Tables 11a and 11b present the estimated total direct and total indirect emissions, respectively, for the air pollutants tracked in this inventory. In the direct emissions category (Table 11a), all action alternatives have total direct emissions across pollutants in a similar order of magnitude, ranging from 16,200 to 22,400 metric tons; however, Alternative 3E(7.5) results in the highest air pollutant emissions because of its large dredge volume, followed by Alternatives 2C+(12), 3B(12), 3C+(12), and 2C+(7.5). In the indirect emissions category (Table 11b), Alternative 3E(7.5) also results in a much higher CO_2 indirect emission total (compared to the other four alternatives) because the largest hydraulically dredged volume is associated with this alternative, which in turn results in the largest volume of water treated, electricity consumed, and therefore, indirect emissions. Across alternatives and emission categories, CO_2 accounts for an approximate average of 99% of the total pollutant mass, with the remaining seven pollutants accounting for 1%. A stacked bar chart under these tables graphically presents the CO_2 emission results by scope.

Table 12 presents direct CO_2 emissions totaled by the activities tracked in this inventory (site preparation, sediment removal, transloading and disposal, material placement, and long-term monitoring). A series of pie charts are also provided under Table 12, depicting the relative contribution to overall CO_2 emissions from these five activity categories[12].
Alternative 3E(7.5) has the largest CO_2 emissions among the alternatives in most activity categories (especially sediment removal [3,100 metric tons] and transloading/disposal

[12] The direct CO_2 emissions contribution estimated from long-term monitoring activities resulted each in less than one-tenth of one percent of the total and, therefore, they are not discernible in the pie charts.

[15,000 metric tons]), for an overall total of 22,700 metric tons. With the exception of Alternative 1A(12) (which addresses underpier areas with MNR), all other alternatives include comparable levels of material placement (for RMC, ENR, capping, and in situ treatment), and therefore, have CO_2 emissions in the material placement activity category on an average of 3,500 metric tons. CO_2 emissions due to site preparation and long-term monitoring activities are very similar among alternatives, since they have the same general assumptions. On average, 70% of the total direct CO_2 emissions were estimated to result from the transloading and disposal, followed by material placement (approximately 20%), and sediment removal (approximately 9%) activities.

In addition, approximately 71% to 79% of the emissions of PM_{10}, $PM_{2.5}$, CO_2, and NOx and 27% to 49% for the remaining air pollutants resulted from the transloading, transportation, and disposal by rail of dredged sediments regardless of the alternative (see Table 9). The mass emitted due to the rail transport and disposal component increases proportionally to the volume of dredged sediments (Alternatives 2C+(7.5) and 3E(7.5) have largest dredge volumes [with more than 1 million cubic yards dredged], followed by Alternatives 3B(12), 3C+(12), 2B(12), 2C+(12), and lastly, by Alternatives 1A(12), 1B(12), and 1C+(12)). Not only are larger volumes of dredged sediment generated for disposal, compared to the volumes of material needed for placement (approximately three to four times), but also the distance travelled is a key factor (284 miles by train [for sediment disposal to landfill] versus 20 miles by truck and barge from quarry to the EW [for material placement]) (Table 1).

The impacts of train, truck, and barge transport are based on their specific diesel fuel economies (400, 34, and 213 ton-mile/gal, respectively; see Tables 3, 4, and 5) and the distances that would be required for each activity.

When based on diesel fuel economy, rail transport is nearly twice as efficient as tug/barge transport, and more than ten times more efficient than truck transport. However, when considering combined tonnages and travelled distances for the transport of material, air emissions of rail is larger than that of truck and barge for the EW alternatives. This is reflected in the pie charts under Table 12, where emissions due to transloading and disposal (which is primarily rail transport) are approximately 5 times larger than emissions due to material placement (which is primarily truck and barge transport).

Finally, in order to provide some context regarding the GHG emissions estimated for the alternatives, several comparison equivalencies have been summarized in Table 13. This table illustrates the magnitude of other activities that would result in CO_2 emissions equivalent to the CO emissions estimated for each alternative. Specifically, the number of passenger vehicles that would emit an equivalent quantity of CO_2-eq in 1 year, the number of barrels of oil consumed that would emit an equivalent amount of CO_2, and the number of homes from which the annual energy use would result in an equivalent amount of CO_2 emitted, are presented in this table.

5 REFERENCES

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TABLES

Table 1. General Inputs for Direct Emission Calculation

Activity	Type of Vehicle/ Equipment Used	SCC Description	Notes	Equipment Uptime	Equipment Quantity	Total Daily Diesel Usage (gal/day)	Production Rate (quantity/ day)	One-way Distance (miles)	Quantity Units	Quantities by Alternative 1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B12)	3C+(12)	2C+(7.5)	3E(7.5)
SITE PREPARATION																		
Equipment Mobilization/Demobilization (8 hours/day)																		
	Tug Boat (800 HP) 2	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization of 2 derrick rigs and 3 material barges, mob/demob on an annual basis. Assume 8 hrs/day for 35 days per construction season.	0.2	5	120	0.1	na	construction season	9	9	9	10	10	10	10	11	13
Pile Removal (12 hrs/day)																		
	150-ton Crane 1	Diesel Cranes	Assume each work day contains one 12-hr shift. Assume pile removal occurs at 25 piles/day.	0.7	1	101	25	na	# piles	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
	Work Boat 1	Two-stroke Outboard (WB)		0.7	1	13	25	na	# piles	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.2	1	36	25	na	# piles	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
SEDIMENT REMOVAL																		
Open-water Dredging (12 hours/day)																		
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12 hr-shift.	0.7	1	109	1,100	na	cy sediment	813,120	813,120	813,120	902,212	902,212	938,455	938,455	1,007,892	1,016,453
	Work Boat 1	Two-stroke Outboard (WB)		0.7	2	25	1,100	na	cy sediment	813,120	813,120	813,120	902,212	902,212	938,455	938,455	1,007,892	1,016,453
Restricted Access Dredging (Under the West Seattle Bridge) (12 hours/day)																		
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12 hr-shift.	0.7	1	109	270	na	cy sediment	0	0	0	0	0	16,651	16,651	0	19,365
	Push Boat	Two-stroke Outboard (PB)		0.7	1	17	270	na	cy sediment	0	0	0	0	0	16,651	16,651	0	19,365
	Work Boat 1	Two-stroke Outboard (WB)		0.7	2	25	270	na	cy sediment	0	0	0	0	0	16,651	16,651	0	19,365
Diver-assited Hydraulic Dredging (Underpier) (8 hours/day)																		
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 8 hr-shift.	0.7	1	50	40	na	cy sediment	0	0	7,016	0	7,016	0	7,016	7,016	46,216
	Push Boat 2	Two-stroke Outboard (PB)		0.7	1	11	40	na	cy sediment	0	0	7,016	0	7,016	0	7,016	7,016	46,216
	Work Boat 2	Two-stroke Outboard (WB)		0.7	2	17	40	na	cy sediment	0	0	7,016	0	7,016	0	7,016	7,016	46,216
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)																		
	High-solids Pump	Diesel Pumps	Assume each work day contains one 8 hr-shift.	0.8	6	77	40	na	cy sediment	0	0	7,016	0	7,016	0	7,016	7,016	46,216
SEDIMENT TRANSLOADING AND DISPOSAL																		
Mechanical Offloading (12 hours/day)																		
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 12 hr-shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way). Assume sediment disposal by rail to landfill in eastern WA for 284 mi (one-way).	0.2	1	na	na	5	cy sediment	813,120	813,120	820,135	902,212	909,228	955,106	962,121	1,014,908	1,082,034
	100-ton Crane	Diesel Cranes		0.7	2	202	1,100	na	cy sediment	813,120	813,120	820,135	902,212	909,228	955,106	962,121	1,014,908	1,082,034
	Front-end Loader	Diesel Rough Terrain Forklifts		0.8	2	77	1,100	na	cy sediment	813,120	813,120	820,135	902,212	909,228	955,106	962,121	1,014,908	1,082,034
	Rail	na		na	1	na	na	284	cy sediment	813,120	813,120	820,135	902,212	909,228	955,106	962,121	1,014,908	1,082,034

Table 1. General Inputs for Direct Emission Calculation

Activity	Type of Vehicle/ Equipment Used	SCC Description	Notes	Equipment Uptime	Equipment Quantity	Total Daily Diesel Usage (gal/day)	Production Rate (quantity/ day)	One-way Distance (miles)	Quantity Units	Quantities by Alternative								
										1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B12)	3C+(12)	2C+(7.5)	3E(7.5)
CAPPING/TREATMENT MATERIAL PLACEMENT																		
Transportation of Materials to EW																		
	Dump Truck (20-ton) for sand, gravel, and armor	Diesel Off-highway Trucks	Assume sand, gravel, and armor are transported 20 miles from quarry to shore by truck and 20 miles to the site by barge. Assume activated carbon is transported from Toledo (OH) to site by train for a 2,452 mi distance (one-way).	na	1	na	na	20	ton	375,258	376,075	375,986	361,020	360,935	343,806	343,369	373,192	354,937
	Tug Boat (3,000 HP) for sand, gravel, and armor	Diesel Inboard/Sterndrive (3,000 HP)		na	1	na	na	20	ton	375,258	376,075	375,986	361,020	360,935	343,806	343,369	373,192	354,937
	Rail for Activated Carbon	na		na	1	na	na	2,452	cy	0	4,867	4,867	4,867	4,867	4,867	4,867	5,113	5,113
Residuals Management Cover, Capping, Backfill, and Enhanced Natural Recovery (Sand) (12 hours/day)																		
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12 hr-shift.	0.7	1	101	940	na	cy sand	234,151	234,756	234,690	223,604	223,541	229,661	229,338	232,434	237,720
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.2	1	36	940	na	cy sand	234,151	234,756	234,690	223,604	223,541	229,661	229,338	232,434	237,720
	Work Boat 1	Two-stroke Outboard (WB)		0.7	2	25	940	na	cy sand	234,151	234,756	234,690	223,604	223,541	229,661	229,338	232,434	237,720
Capping (Gravel) (12 hours/day)																		
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12 hr-shift.	0.7	1	101	940	na	cy gravel	20,620	20,620	20,620	20,620	20,620	11,769	11,769	20,708	11,857
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.2	1	36	940	na	cy gravel	20,620	20,620	20,620	20,620	20,620	11,769	11,769	20,708	11,857
	Work Boat 1	Two-stroke Outboard (WB)		0.7	2	25	940	na	cy gravel	20,620	20,620	20,620	20,620	20,620	11,769	11,769	20,708	11,857
Capping (Armor) (12 hours/day)																		
	100-ton Crane	Diesel Excavators	Assume each work day contains one 12 hr-shift.	0.7	1	101	560	na	cy armor stone	30,931	30,931	30,931	30,931	30,931	17,654	17,654	31,062	17,786
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.2	1	36	560	na	cy armor stone	30,931	30,931	30,931	30,931	30,931	17,654	17,654	31,062	17,786
	Work Boat 1	Two-stroke Outboard (WB)		0.7	2	25	560	na	cy armor stone	30,931	30,931	30,931	30,931	30,931	17,654	17,654	31,062	17,786
In situ Treatment (Underpier) (12 hours/day)																		
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12 hr-shift.	0.5	1	24	60	na	cy AC	0	4,867	4,867	4,867	4,867	4,867	4,867	5,113	5,113
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.2	1	36	60	na	cy AC	0	4,867	4,867	4,867	4,867	4,867	4,867	5,113	5,113
	Work Boat 1	Two-stroke Outboard (WB)		0.7	2	25	60	na	cy AC	0	4,867	4,867	4,867	4,867	4,867	4,867	5,113	5,113
Enhanced Natural Recovery (Low Bridge) (12 hours/day)																		
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12 hr-shift.	0.5	1	24	60	na	cy sand	811	811	811	1,421	1,421	1,421	1,421	1,562	1,562
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.2	1	36	60	na	cy sand	811	811	811	1,421	1,421	1,421	1,421	1,562	1,562
	Work Boat 1	Two-stroke Outboard (WB)		0.7	2	25	60	na	cy sand	811	811	811	1,421	1,421	1,421	1,421	1,562	1,562

***LONG-TERM MONITORING* (12 hours/day)**																		
	Work Boat 1	Two-stroke Outboard (WB)	Assume each work day contains one 12 hr-shift. Assume a total of 8 monitoring events based on: a pre-construction baseline sampling, a construction monitoring/confirmational sampling, and long-term monitoring at years 1, 3, 5, 10, 15, and 20.	0.7	1	13	0.1	na	monitoring events	8	8	8	8	8	8	8	8	8

Notes:

1. Quantities and production rates by alternative were obtained from Appendix E (Cost Estimate).
2. Equipment and daily equipment operation rates assumed based on best professional judgment and experience in similar sediment projects.

AC = activated carbon; cy = cubic yard; ENR = enhanced natural recovery; EW = East Waterway; gal = gallon; HP = horse power; hr = hour; na = not applicable; PB = push boat; RMC = residuals management cover; SCC = Standard Classification Code; WB = work boat

Table 2. Equipment Type and Fuel Usage Assumptions per Equipment

Equipment Type	Equipment Uptime (%)	Equipment Daily Use - Work Day (hours/day)	Fuel Consumption Rate (gal/hour)	Daily Diesel Fuel Usage (gal/day)
Hydraulic Excavator	70%	8	9	50
Front-end Loader	80%	12	4	38
150-ton Crane 1	70%	12	12	101
150-ton Crane 2	70%	8	12	67
100-ton Crane	70%	12	12	101
Derrick Rig	70%	12	13	109
Telebelt	50%	12	4	24
High-solids Pump	80%	8	2	13
Tug Boat (3,000 HP)	20%	12	40	96
Tug Boat (800 HP)	20%	12	15	36
Tug Boat (800 HP) 2	20%	8	15	24
Push Boat	70%	12	2	17
Push Boat 2	70%	8	2	11
Work Boat 1	70%	12	1.5	13
Work Boat 2	70%	8	1.5	8

Notes:
1. Equipment uptimes (effective operation time) and fuel consumption rates were estimated for each equipment based on best professional judgment and experience on other similar sediment projects.
2. Daily use of equipment is based on assumptions provided in Appendix E (Cost Estimate).
3. Daily diesel fuel usage is calculated as fuel consumption rate (gal/hour) x equipment uptime (%) x work day (hours/day).
4. Daily diesel fuel usage is calculated for a single piece of equipment. Assumed number pieces of equipment is presented in Table 1.
gal = gallon; HP = horsepower

Table 3. Rail Transportation Assumptions

Parameter	Value	Unit	Comments/Reference
Diesel fuel economy for train/locomotive	400	ton-mi/gal	National average fuel consumption rate of 400 ton-miles/gallon based from data collected by the Association of American Railroads, as discussed on page 3 of EPA Technical Highlights "Emission Factors for Locomotives" (April 2009; Office of Transportation and Air Quality [OTAQ]; EPA-420-F-09-025).
Emission Factors			Source: EPA Technical Highlights "Emission Factors for Locomotives" (April 2009; Office of Transportation and Air Quality [OTAQ]; EPA-420-F-09-025)
Hydrocarbons (HC)	0.26	g/bhp-hr	Emission factors for rail transportation (for Tier 2 Locomotives) are available in Table 1 (pg.2) of Line-Haul Emission Factors. Tier 2 corresponds to locomotives manufactured between 2005 and 2011, which is a reasonable assumption by the time the EW project is implemented. Emission factors as following: HC = 0.26 g/bhp-hr, NO_X = 4.95 g/bhp-hr, PM_{10} = 0.18 g/bhp-hr, and CO = 1.28 g/bhp-hr. In order to use emission factors in g/gal, as conversion factor of 20.8 bhp-hr/gal (for Large Line Haul and Passenger Locomotives) is available in Table 3. VOC emissions are 1.053 times HC emissions and $PM_{2.5}$ emissions are 0.97 times PM_{10} emissions (pg.4). SO_2 emissions are dependent upon fuel properties and not engine properties (pg.5): SO_2 (g/gal) = (fuel density) x (conversion factor) x (64 g SO_2/32 g S) x (S content of fuel) The current density of diesel fuel is 0.832 kg/L (3,150 g/gal) (http://ies.jrc.ec.europa.eu/uploads/media/TTW_Report_010307.pdf). The current sulfur content of diesel fuel is 15 ppm (ultra-low-sulfur diesel fuel; https://www.epa.gov/aboutepa/reduced-sulfur-content-diesel-fuel). The fraction of fuel sulfur converted to SO_2 is 97.8% (pg.5). Therefore, SO_2 (g/gal) = (3,150 g/gal) x (0.978) x (64 g SO_2 / 32 g S) x (15e-6) = 0.092 g/gal The CO_2 emission factor is 10.21 kg CO_2/gal, as in Table 2 - "CO_2 Emissions for Transportation Fuels for Road Vehicles, Locomotives, and Aircraft" from Emission Factors for Greenhouse Gas Inventories November 2011)
	5.41	g/gal	
Volatile Organic Compounds (VOCs)	0.27	g/bhp-hr	
	5.69	g/gal	
Carbon Monoxide (CO)	1.28	g/bhp-hr	
	26.62	g/gal	
Nitrous Oxides (NO_X)	4.95	g/bhp-hr	
	102.96	g/gal	
Particulate Matter 10 µm (PM_{10})	0.18	g/bhp-hr	
	3.74	g/gal	
Particulate Matter 2.5 µm ($PM_{2.5}$)	0.1746	g/bhp-hr	
	3.63	g/gal	
Sulfur Dioxide (SO_2)	0.092	g/gal	
Carbon Dioxide (CO_2)	10,210	g/gal	
Distance from shore to Subtitle D landfill (Roosevelt, WA)	284	miles	Sediment is assumed to be transferred from an on-shore offloading facility in Seattle, WA to the landfill in Roosevelt, WA.
Distance from activated carbon vendor (Toledo, OH) to EW	2452	miles	Activated carbon is assumed to be transported from a vendor in Toledo, OH to EW.

Notes:
1. Ton-mile is a unit of freight transportation equivalent to a ton of freight moved 1 mile.

bph = usable power; EW = East Waterway; g = gram; gal = gallon; hr = hour; kg = kilogram; L = liter; mi = mile; ppm = parts per million

Table 4. Truck Transportation Assumptions

Parameter	Value	Unit	Comments/Reference
Dump Truck			Assumed truck capacity and fuel consumption based on best professional judgement and experience on other similar sediment projects.
Average power	600	hp	
Capacity	20	tons	
Fuel consumption	13	gal/hr	
CO_2 emission factor for diesel fuel	10.21	kg CO_2/gal	Source: Table 2 - "CO_2 Emissions for Transportation Fuels for Road Vehicles, Locomotives, and Aircraft" from *Emission Factors for Greenhouse Gas Inventories,* November 2011
CO_2 emission factor for trucks	0.297	kg CO_2/ton-mile	Source: Table 9 - "Product Transport Emission Factors" from *Emission Factors for Greenhouse Gas Inventories* November 2011
Diesel fuel economy for trucks	34	ton-mile/gallon	Calculated as 10.21 kg/gal / 0.297 kg/ton-mi ≈ 34 ton-mile / gal
Emission Factors			Estimates of average in-use emission factors and other information from EPA's NONROAD2008a model for the 2013 calendar year (includes all model years present in the 2013 fleet). This information is found in the MS Excel File "2013 National Avg emissions factors.xls", which was provided by an EPA NONROAD representative. Emission factors from the NONROAD08 spreadsheet were chosen based on equipment type and estimated fuel consumption rate, which is based on horsepower (HP).
Hydrocarbons (HC)	3.02	g/gal	
Volatile Organic Compounds (VOCs)	3.18	g/gal	
Carbon Monoxide (CO)	18.05	g/gal	
Nitrous Oxides (NO_X)	44.56	g/gal	
Particulate Matter 10 µm (PM_{10})	2.92	g/gal	
Particulate Matter 2.5 µm ($PM_{2.5}$)	2.92	g/gal	
Sulfur Dioxide (SO_2)	0.18	g/gal	
Carbon Dioxide (CO_2)	10,210	g/gal	

Notes:

1. Ton-mile is a unit of freight transportation equivalent to a ton of freight moved 1 mile.
2. Emission factors are deduced by interpolating fuel consumption rate of 13 gal/hour for a dump truck into the 2013 EPA NONROAD Emission Factors.

g = gram; gal = gallon; hp = horsepower; hr = hour; kg = kilogram; mi = mile

Table 5. Barge Transportation Assumptions

Parameter	Value	Unit	Comments/Reference
Tug/barge - Diesel Inboard/Sterndrive (3,000 HP)			Average fuel consumption of empty and fully loaded tug/barge: (15+85)/2 = 50, rounded down to 40 gal/hour in order to use NONROAD EPA emission factors. Empty tug/barges typically consume 15 gal/hour. Fully loaded tug/barges consume 85 gal/hour in Seattle area, derived from 1999 Puget Sound Clean Air Agency (www.pscleanair.org) document entitled "1999 TUGBOAT FUEL CONSUMPTION IN SEATTLE AREA" http://www.epa.gov/ttn/chief/conference/ei11/poster/agyei.pdf
Average power	3000	hp	
Fuel consumption	40	gal/hr	
CO_2 emission factor for diesel fuel	10.21	kg CO_2/gal	Source: Table 2 - "CO2 Emissions for Transportation Fuels for Road Vehicles, Locomotives, and Aircraft" from *Emission Factors for Greenhouse Gas Inventories* November 2011)
CO_2 emission factor for boats	0.048	kg CO_2/ton-mile	Source: Table 9 - "Product Transport Emission Factors" from *Emission Factors for Greenhouse Gas Inventories* November 2011
Diesel fuel economy for boats	213	ton-mile / gallon	Calculated as 10.21 kg/gal / 0.048 kg/ton-mi ≈ 213 ton-mile/gal
Emission Factors			Estimates of average in-use emission factors and other information from EPA's NONROAD2008a model for the 2013 calendar year (includes all model years present in the 2013 fleet). This information is found in the MS Excel File "2013 National Avg emissions factors.xls", which was provided by an EPA NONROAD representative. Emission factors from the NONROAD08 spreadsheet were chosen based on equipment type and estimated fuel consumption rate, which is based on horsepower (hp).
Hydrocarbons (HC)	4.88	g/gal	
Volatile Organic Compounds (VOCs)	5.14	g/gal	
Carbon Monoxide (CO)	20.07	g/gal	
Nitrous Oxides (NO_X)	117.05	g/gal	
Particulate Matter 10 µm (PM_{10})	2.14	g/gal	
Particulate Matter 2.5 µm ($PM_{2.5}$)	2.14	g/gal	
Sulfur Dioxide (SO_2)	0.28	g/gal	
Carbon Dioxide (CO_2)	10,210	g/gal	
Distance from EW to offloading area (LaFarge) - for open-water dredging activity	5	miles	Sediment is assumed to be transported by barge to an offloading area in Lafarge, which is 5 miles from middle point of the EW. LaFarge is currently approved by EPA as an offloading area of dredged sediment for other local projects.
Distance from shore to EW - for material placement activity	20	miles	Sand, gravel, and armor are assumed to be transported by barge from shore to EW.

Notes:
1. Ton-mile is a unit of freight transportation equivalent to a ton of freight moved 1 mile.
2. Emission factors are deduced by interpolating fuel consumption rate of 40 gal/hour for a tug/barge into the 2013 EPA NONROAD Emission Factors.
EW = East Waterway; g = gram; gal = gallon; hp = horsepower; hr = hour; kg = kilogram; mi = mile

Table 6. General Inputs for Indirect Emission Calculation

Activity	Type of Equipment	Notes	Electricity Consumption Rate (kW)	Production Rate (quantity/ day)	Quantity Units	Quantity Inputs by Alternative								
						1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
SEDIMENT REMOVAL														
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)														
	Water Treatment System	Assumed one 8-hour shift. Assumed electricity usage for water treatment of hydraulically dredged sediments.	250	40	cy sediment	0	0	7,016	0	7,016	0	7,016	7,016	46,216

Notes:

1. Quantities and production rate by alternative were obtained from Appendix E (Cost Estimate).

cy = cubic yard; kW = kilowatt

Table 7. Electricity Assumptions

Parameter		Value	Unit	Comments/Reference
Energy consumption rate		250	kW	Estimated consumption rate of 250 kW of the water treatment system for hydraulically dredged sediments based on best professional judgement and experience on other similar sediment projects.
Emission Factors				Source: EPA guidance document "The Emissions & Generation Resource Integrated Database, Technical Support Document for eGRID with Year 2012 Data (eGRID2012) " (Office of Atmospheric Programs, Clean Air Markets Division, October 2015). (http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html) Subregion: NWPP (WECC Northwest). Emission factors in lb/MWh units are converted to g/MWh for consistency of overall emission inventory.
	Carbon Dioxide (CO_2)	665.75	lb/MWh	
		301977.5	g/MWh	
	Nitrous Oxides (NO_X)	0.7240	lb/MWh	
		328.4	g/MWh	
	Sulfur Dioxide (SO_2)	0.7587	lb/MWh	
		344.1	g/MWh	

Notes:

g = gram; hr = hour; kW = kilowatt; lb = pound; MWh = megawatt-hour; NWPP = North West Power Pool; WECC = Western Electricity Coordinating Council

Table 8. Emission Factors for Construction Equipment and Vehicles

Type of Vehicle/Equipment Used	SCC Description	Fuel Consumption Rate (gal/hour)	Emission Factors (g/gal)							
			Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrous Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
Work Boat	Two-stroke Outboard (WB)	1.5	423.15	437.53	982.49	29.01	8.72	8.72	1.55	7,556
Push Boat	Two-stroke Outboard (PB)	2	321.77	332.71	1,009.34	37.16	6.36	6.36	1.62	7,885
100-ton Crane, 150-ton Crane, Derrick Rig	Diesel Cranes	12	4.01	4.23	22.03	75.76	3.05	3.05	0.19	10,261
Hydraulic Excavator	Diesel Excavators	9	3.46	3.64	17.63	49.06	3.09	3.09	0.18	10,263
Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)	15	5.26	5.54	19.98	110.88	2.12	2.12	0.28	10,257
Telebelt	Diesel Other Material Handling Equipment	4	13.32	14.02	54.23	95.51	8.48	8.48	0.19	10,231
High Solids Pump	Diesel Pumps	2	9.88	10.41	49.40	89.34	8.96	8.96	0.20	10,242
Front-end Loader	Diesel Rough Terrain Forklifts	4	5.06	5.33	24.53	64.55	5.26	5.26	0.19	10,257

Notes:

1. Estimates of average in-use emission factors and other information from EPA's NONROAD model for the 2013 calendar year (includes all model years present in the 2013 fleet). This information is found in the MS Excel File "2013 National Avg emissions factors.xls", which was provided by an EPA NONROAD official (EPA 2013b). Emission factors from the NONROAD spreadsheet were derived based on selected equipment type, and estimated fuel consumption rate (according to designated horsepower).
2. Emission factors are deduced by interpolating the fuel consumption rate (gal/hour) for the specific equipment (based on its SCC description) into the NONROAD excel spreadsheet.

CO = carbon monoxide; CO_2 = carbon dioxide; g = gram; gal = gallon; HP = horsepower; NO_X = nitrogen oxides (NO and NO_2); PB = push boat; $PM_{2.5}$ = particulate matter less that 2.5 microns in diameter; PM_{10} = particulate matter less than 10 microns in diameter; SCC = Standard Classification Code; SO_2 = sulfur dioxide; VOC = volatile organic compounds; WB = work boat

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 1A(12) - Total Emissions (tonnes)							
				Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP) 2	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization of 2 derrick rigs and 3 material barges, mob/demob on an annual basis. Assume 8 hrs/day for 35 days per construction season.	0.0663	0.0698	0.2518	1.397	0.02677	0.02677	0.00348	129.2
Pile Removal (12 hrs/day)											
	150-ton Crane 1	Diesel Cranes	Assume each work day contains one 12-hr shift. Assume pile removal occurs at 25 piles/day.	0.0162	0.0170	0.0888	0.3055	0.0123	0.0123	0.0008	41.3718
	Work Boat 1	Two-stroke Outboard (WB)		0.2133	0.2205	0.4952	0.0146	0.0044	0.0044	0.0008	3.8084
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0076	0.0080	0.0288	0.1597	0.0031	0.0031	0.0004	14.7696
			SUBTOTAL EMISSIONS - SITE PREPARATION	**0.303**	**0.315**	**0.865**	**1.877**	**0.047**	**0.047**	**0.005**	**189**
SEDIMENT REMOVAL											
Open-water Dredging (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.3241	0.3412	1.7786	6.1157	0.2464	0.2464	0.0153	828.2630
	Work Boat 1	Two-stroke Outboard (WB)		7.8823	8.1503	18.3016	0.5403	0.1624	0.1624	0.0289	140.7597
Restricted Access Dredging (Under the West Seattle Bridge) (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Push Boat	Two-stroke Outboard (PB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Work Boat 1	Two-stroke Outboard (WB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydraulic Dredging (Underpiers) (8 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 8-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Push Boat 2	Two-stroke Outboard (PB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Work Boat 2	Two-stroke Outboard (WB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)											
	High-solids Pump	Diesel Pumps	Assume each work day contains one 8-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			SUBTOTAL EMISSIONS - SEDIMENT REMOVAL	**8.21**	**8.49**	**20**	**6.66**	**0.41**	**0.41**	**0.04**	**969**
SEDIMENT TRANSLOADING AND DISPOSAL											
Mechanical Offloading (12 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 12-hr shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way). Assume sediment disposal by rail to landfill in eastern WA for 284 mi (one-way).	0.1398	0.1472	0.5753	3.3559	0.0614	0.0614	0.0079	292.7231
	100-ton Crane	Diesel Cranes		0.5983	0.6300	3.2835	11.2905	0.4549	0.4549	0.0282	1529.1010
	Front-end Loader	Diesel Rough Terrain Forklifts		0.2872	0.3025	1.3928	3.6645	0.2988	0.2988	0.0108	582.3185
	Rail	na		4.6832	4.9314	23.0557	89.1605	3.2422	3.1449	0.0797	8841.5807
			SUBTOTAL EMISSIONS - SEDIMENT TRANSLOADING AND DISPOSAL	**5.71**	**6.01**	**28**	**107**	**4.06**	**3.96**	**0.13**	**11,246**

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 1A(12) - Total Emissions (tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
CAPPING/TREATMENT MATERIAL PLACEMENT											
Transportation of Materials to EW											
	Dump Truck (20-ton) for sand, gravel, and armor	Diesel Off-highway Trucks	Assume sand, gravel, and armor are transported 20 miles from quarry to shore by truck and 20 miles to the site by barge. Assume activated carbon is transported from Toledo (OH) to site by train for a 2,452 mi distance (one-way).	0.6596	0.6945	3.9408	9.7287	0.6379	0.6379	0.0390	2229.0318
	Tug Boat (3,000 HP) for sand, gravel, and armor	Diesel Inboard/Sterndrive (3,000 HP)		0.1721	0.1812	0.7080	4.1300	0.0756	0.0756	0.0098	360.2476
	Rail for Activated Carbon	na		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Residuals Management Cover, Capping, Backfill, and Enhanced Natural Recovery (Sand) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.1008	0.1061	0.5532	1.9023	0.0766	0.0766	0.0048	257.6390
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0472	0.0497	0.1792	0.9943	0.0190	0.0190	0.0025	91.9765
	Work Boat 1	Two-stroke Outboard (WB)		2.6562	2.7465	6.1673	0.1821	0.0547	0.0547	0.0097	47.4333
Capping (Gravel) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0089	0.0093	0.0487	0.1675	0.0067	0.0067	0.0004	22.6889
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0042	0.0044	0.0158	0.0876	0.0017	0.0017	0.0002	8.0999
	Work Boat 1	Two-stroke Outboard (WB)		0.2339	0.2419	0.5431	0.0160	0.0048	0.0048	0.0009	4.1772
Capping (Armor) (12 hours/day)											
	100-ton Crane	Diesel Excavators	Assume each work day contains one 12-hr shift.	0.0224	0.0235	0.1227	0.4218	0.0170	0.0170	0.0011	57.1273
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0105	0.0110	0.0397	0.2205	0.0042	0.0042	0.0005	20.3943
	Work Boat 1	Two-stroke Outboard (WB)		0.5890	0.6090	1.3675	0.0404	0.0121	0.0121	0.0022	10.5176
In situ Treatment (Activated Carbon, Underpier) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Work Boat 1	Two-stroke Outboard (WB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Enhanced Natural Recovery (Low Bridge) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0043	0.0045	0.0176	0.0310	0.0027	0.0027	0.0001	3.3177
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0026	0.0027	0.0097	0.0539	0.0010	0.0010	0.0001	4.9891
	Work Boat 1	Two-stroke Outboard (WB)		0.1441	0.1490	0.3345	0.0099	0.0030	0.0030	0.0005	2.5729
			SUBTOTAL EMISSIONS - MATERIAL PLACEMENT	**4.66**	**4.83**	**14**	**18**	**0.92**	**0.92**	**0.07**	**3,120**
LONG-TERM MONITORING **(12 hours/day)**											
	Work Boat 1	Two-stroke Outboard (WB)	Assume each work day contains one 12 hr-shift. Assume a total of 8 monitoring events based on: a pre-construction baseline sampling, a construction monitoring/confirmational sampling, and long-term monitoring at years 1, 3, 5, 10, 15, and 20.	0.30	0.31	0.69	0.020	0.0062	0.0062	0.0011	5.3
			SUBTOTAL EMISSIONS - LONG-TERM MONITORING	**0.30**	**0.31**	**0.69**	**0.020**	**0.0062**	**0.0062**	**0.0011**	**5.3**
			TOTAL EMISSIONS (metric tons, rounded)	**19**	**20**	**64**	**130**	**5.4**	**5.3**	**0.25**	**16,000**

General Notes:

1. Total emissions for construction equipment/vehicle are calculated as total daily diesel usage (gal/day) / production rate (units/day) x units x emission factor (g/gal) x (1E-6 metric ton/g).
2. Total emissions for rail transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   2a. Total diesel usage for train (gal) is calculated as total tonnage-distance covered (ton-mi) / train fuel economy (ton-mi/gal).
   2b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
3. Total emissions for truck transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   3a. Total diesel usage for trucks (gal) is calculated as total tonnage-distance covered (ton-mi) / truck fuel economy (ton-mi/gal).
   3b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
4. Total emissions for barge transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   4a. Total diesel usage for boats (gal) is calculated as total tonnage-distance covered (ton-mi) / barge fuel economy (ton-mi/gal).
   4b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.

AC = activated carbon; CO = carbon monoxide; CO_2 = carbon dioxide; cy = cubic yard; ENR = enhanced natural recovery; GAC = granular activated carbon; gal = gallon; HP = horse power; na = not applicable; NO_X = nitrogen oxides (NO and NO_2); PB = push boat; $PM_{2.5}$ = particulate matter less that 2.5 microns in diameter; PM_{10} = particulate matter less than 10 microns in diameter; RMC = residuals management cover; SCC = Standard Classification Code; SO_2 = sulfur dioxide; VOC = volatile organic compounds; WB = work boat

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 1B(12) - Total Emissions (tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP) 2	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization of 2 derrick rigs and 3 material barges, mob/demob on an annual basis. Assume 8 hrs/day for 35 days per construction season.	0.0663	0.0698	0.2518	1.397	0.02677	0.02677	0.00348	129.2
Pile Removal (12 hrs/day)											
	150-ton Crane 1	Diesel Cranes	Assume each work day contains one 12-hr shift. Assume pile removal occurs at 25 piles/day.	0.0162	0.0170	0.0888	0.3055	0.0123	0.0123	0.0008	41.3718
	Work Boat 1	Two-stroke Outboard (WB)		0.2133	0.2205	0.4952	0.0146	0.0044	0.0044	0.0008	3.8084
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0076	0.0080	0.0288	0.1597	0.0031	0.0031	0.0004	14.7696
			SUBTOTAL EMISSIONS - SITE PREPARATION	**0.3033**	**0.3153**	**0.8646**	**1.8768**	**0.0465**	**0.0465**	**0.0054**	**189.1842**
SEDIMENT REMOVAL											
Open-water Dredging (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.3241	0.3412	1.7786	6.1157	0.2464	0.2464	0.0153	828.2630
	Work Boat 1	Two-stroke Outboard (WB)		7.8823	8.1503	18.3016	0.5403	0.1624	0.1624	0.0289	140.7597
Restricted Access Dredging (Under the West Seattle Bridge) (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Push Boat	Two-stroke Outboard (PB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Work Boat 1	Two-stroke Outboard (WB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydraulic Dredging (Underpiers) (8 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 8-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Push Boat 2	Two-stroke Outboard (PB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Work Boat 2	Two-stroke Outboard (WB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)											
	High-solids Pump	Diesel Pumps	Assume each work day contains one 8-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			SUBTOTAL EMISSIONS - SEDIMENT REMOVAL	**8.2**	**8.5**	**20**	**7**	**0.41**	**0.41**	**0.044**	**969**
SEDIMENT TRANSLOADING AND DISPOSAL											
Mechanical Offloading (12 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 12-hr shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way). Assume sediment disposal by rail to landfill in eastern WA for 284 mi (one-way).	0.1398	0.1472	0.5753	3.3559	0.0614	0.0614	0.0079	292.7231
	100-ton Crane	Diesel Cranes		0.5983	0.6300	3.2835	11.2905	0.4549	0.4549	0.0282	1529.1010
	Front-end Loader	Diesel Rough Terrain Forklifts		0.2872	0.3025	1.3928	3.6645	0.2988	0.2988	0.0108	582.3185
	Rail	na		4.6832	4.9314	23.0557	89.1605	3.2422	3.1449	0.0797	8841.5807
			SUBTOTAL EMISSIONS - SEDIMENT TRANSLOADING AND DISPOSAL	**5.7**	**6.0**	**28**	**107**	**4.1**	**4.0**	**0.13**	**11,246**

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 1B(12) - Total Emissions (tonnes)							
				Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
CAPPING/TREATMENT MATERIAL PLACEMENT											
Transportation of Materials to EW											
	Dump Truck (20-ton) for sand, gravel, and armor	Diesel Off-highway Trucks	Assume sand, gravel, and armor are transported 20 miles from quarry to shore by truck and 20 miles to the site by barge. Assume activated carbon is transported from Toledo (OH) to site by train for a 2,452 mi distance (one-way).	0.6610	0.6960	3.9494	9.7499	0.6393	0.6393	0.0391	2233.8843
	Tug Boat (3,000 HP) for sand, gravel, and armor	Diesel Inboard/Sterndrive (3,000 HP)		0.1725	0.1816	0.7096	4.1390	0.0758	0.0758	0.0098	361.0318
	Rail for Activated Carbon	na		0.2420	0.2548	1.1914	4.6076	0.1675	0.1625	0.0041	456.9064
Residuals Management Cover, Capping, Backfill, and Enhanced Natural Recovery (Sand) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.1011	0.1064	0.5547	1.9073	0.0768	0.0768	0.0048	258.3048
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0473	0.0498	0.1797	0.9968	0.0191	0.0191	0.0025	92.2142
	Work Boat 1	Two-stroke Outboard (WB)		2.6631	2.7536	6.1832	0.1825	0.0549	0.0549	0.0097	47.5559
Capping (Gravel) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0089	0.0093	0.0487	0.1675	0.0067	0.0067	0.0004	22.6889
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0042	0.0044	0.0158	0.0876	0.0017	0.0017	0.0002	8.0999
	Work Boat 1	Two-stroke Outboard (WB)		0.2339	0.2419	0.5431	0.0160	0.0048	0.0048	0.0009	4.1772
Capping (Armor) (12 hours/day)											
	100-ton Crane	Diesel Excavators	Assume each work day contains one 12-hr shift.	0.0224	0.0235	0.1227	0.4218	0.0170	0.0170	0.0011	57.1273
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0105	0.0110	0.0397	0.2205	0.0042	0.0042	0.0005	20.3943
	Work Boat 1	Two-stroke Outboard (WB)		0.5890	0.6090	1.3675	0.0404	0.0121	0.0121	0.0022	10.5176
In situ Treatment (Activated Carbon, Underpier) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0259	0.0273	0.1056	0.1859	0.0165	0.0165	0.0004	19.9174
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0154	0.0162	0.0584	0.3238	0.0062	0.0062	0.0008	29.9508
	Work Boat 1	Two-stroke Outboard (WB)		0.8650	0.8944	2.0083	0.0593	0.0178	0.0178	0.0032	15.4460
Enhanced Natural Recovery (Low Bridge) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0043	0.0045	0.0176	0.0310	0.0027	0.0027	0.0001	3.3177
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0026	0.0027	0.0097	0.0539	0.0010	0.0010	0.0001	4.9891
	Work Boat 1	Two-stroke Outboard (WB)		0.1441	0.1490	0.3345	0.0099	0.0030	0.0030	0.0005	2.5729
			SUBTOTAL EMISSIONS - MATERIAL PLACEMENT	**5.8**	**6.0**	**17**	**23**	**1.1**	**1.1**	**0.08**	**3,649**
LONG-TERM MONITORING (12 hours/day)											
	Work Boat 1	Two-stroke Outboard (WB)	Assume each work day contains one 12 hr-shift. Assume a total of 8 monitoring events based on: a pre-construction baseline sampling, a construction monitoring/confirmational sampling, and long-term monitoring at years 1, 3, 5, 10, 15, and 20.	0.30	0.31	0.69	0.020	0.0062	0.0062	0.0011	5.3
			SUBTOTAL EMISSIONS - LONG-TERM MONITORING	**0.30**	**0.31**	**0.69**	**0.020**	**0.0062**	**0.0062**	**0.0011**	**5.3**
			TOTAL EMISSIONS (metric tons, rounded)	**20**	**21**	**67**	**140**	**5.6**	**5.5**	**0.26**	**16,000**

General Notes:

1. Total emissions for construction equipment/vehicle are calculated as total daily diesel usage (gal/day) / production rate (units/day) x units x emission factor (g/gal) x (1E-6 metric ton/g).
2. Total emissions for rail transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   2a. Total diesel usage for train (gal) is calculated as total tonnage-distance covered (ton-mi) / train fuel economy (ton-mi/gal).
   2b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
3. Total emissions for truck transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   3a. Total diesel usage for trucks (gal) is calculated as total tonnage-distance covered (ton-mi) / truck fuel economy (ton-mi/gal).
   3b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
4. Total emissions for barge transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   4a. Total diesel usage for boats (gal) is calculated as total tonnage-distance covered (ton-mi) / barge fuel economy (ton-mi/gal).
   4b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.

AC = activated carbon; CO = carbon monoxide; CO_2 = carbon dioxide; cy = cubic yard; ENR = enhanced natural recovery; GAC = granular activated carbon; gal = gallon; HP = horse power; na = not applicable; NO_X = nitrogen oxides (NO and NO_2); PB = push boat; $PM_{2.5}$ = particulate matter less that 2.5 microns in diameter; PM_{10} = particulate matter less than 10 microns in diameter; RMC = residuals management cover; SCC = Standard Classification Code; SO_2 = sulfur dioxide; VOC = volatile organic compounds; WB = work boat

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 1C+(12) - Total Emissions (tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP) 2	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization of 2 derrick rigs and 3 material barges, mob/demob on an annual basis. Assume 8 hrs/day for 35 days per construction season.	0.0663	0.0698	0.2518	1.397	0.02677	0.02677	0.00348	129.2
Pile Removal (12 hrs/day)											
	150-ton Crane 1	Diesel Cranes	Assume each work day contains one 12-hr shift. Assume pile removal occurs at 25 piles/day.	0.0162	0.0170	0.0888	0.3055	0.0123	0.0123	0.0008	41.3718
	Work Boat 1	Two-stroke Outboard (WB)		0.2133	0.2205	0.4952	0.0146	0.0044	0.0044	0.0008	3.8084
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0076	0.0080	0.0288	0.1597	0.0031	0.0031	0.0004	14.7696
			SUBTOTAL EMISSIONS - SITE PREPARATION	**0.3033**	**0.3153**	**0.8646**	**1.8768**	**0.0465**	**0.0465**	**0.0054**	**189.1842**
SEDIMENT REMOVAL											
Open-water Dredging (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.3241	0.3412	1.7786	6.1157	0.2464	0.2464	0.0153	828.2630
	Work Boat 1	Two-stroke Outboard (WB)		7.8823	8.1503	18.3016	0.5403	0.1624	0.1624	0.0289	140.7597
Restricted Access Dredging (Under the West Seattle Bridge) (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Push Boat	Two-stroke Outboard (PB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Work Boat 1	Two-stroke Outboard (WB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydraulic Dredging (Underpiers) (8 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 8-hr shift.	0.0306	0.0322	0.1559	0.4337	0.0273	0.0273	0.0016	90.7183
	Push Boat 2	Two-stroke Outboard (PB)		0.6321	0.6536	1.9827	0.0730	0.0125	0.0125	0.0032	15.4892
	Work Boat 2	Two-stroke Outboard (WB)		1.2468	1.2892	2.8950	0.0855	0.0257	0.0257	0.0046	22.2654
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)											
	High-solids Pump	Diesel Pumps	Assume each work day contains one 8-hr shift.	0.1331	0.1402	0.6655	1.2034	0.1206	0.1206	0.0026	137.9580
			SUBTOTAL EMISSIONS - SEDIMENT REMOVAL	**10.2**	**10.6**	**26**	**8**	**0.59**	**0.59**	**0.056**	**1,235**
SEDIMENT TRANSLOADING AND DISPOSAL											
Mechanical Offloading (12 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 12-hr shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way). Assume sediment disposal by rail to landfill in eastern WA for 284 mi (one-way).	0.1410	0.1485	0.5803	3.3849	0.0619	0.0619	0.0080	295.2488
	100-ton Crane	Diesel Cranes		0.6034	0.6354	3.3119	11.3879	0.4588	0.4588	0.0285	1542.2941
	Front-end Loader	Diesel Rough Terrain Forklifts		0.2897	0.3051	1.4048	3.6961	0.3014	0.3014	0.0109	587.3427
	Rail	na		4.7236	4.9739	23.2546	89.9298	3.2702	3.1721	0.0804	8917.8661
			SUBTOTAL EMISSIONS - SEDIMENT TRANSLOADING AND DISPOSAL	**5.8**	**6.1**	**29**	**108**	**4.1**	**4.0**	**0.13**	**11,343**

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 1C+(12) - Total Emissions (tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
CAPPING/TREATMENT MATERIAL PLACEMENT											
Transportation of Materials to EW											
	Dump Truck (20-ton) for sand, gravel, and armor	Diesel Off-highway Trucks	Assume sand, gravel, and armor are transported 20 miles from quarry to shore by truck and 20 miles to the site by barge. Assume activated carbon is transported from Toledo (OH) to site by train for a 2,452 mi distance (one-way).	0.6609	0.6959	3.9485	9.7476	0.6391	0.6391	0.0391	2233.3547
	Tug Boat (3,000 HP) for sand, gravel, and armor	Diesel Inboard/Sterndrive (3,000 HP)		0.1724	0.1816	0.7094	4.1380	0.0757	0.0757	0.0098	360.9462
	Rail for Activated Carbon	na		0.2420	0.2548	1.1914	4.6076	0.1675	0.1625	0.0041	456.9066
Residuals Management Cover, Capping, Backfill, and Enhanced Natural Recovery (Sand) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.1010	0.1064	0.5545	1.9067	0.0768	0.0768	0.0048	258.2321
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0473	0.0498	0.1796	0.9966	0.0191	0.0191	0.0025	92.1883
	Work Boat 1	Two-stroke Outboard (WB)		2.6623	2.7528	6.1815	0.1825	0.0548	0.0548	0.0097	47.5425
Capping (Gravel) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0089	0.0093	0.0487	0.1675	0.0067	0.0067	0.0004	22.6889
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0042	0.0044	0.0158	0.0876	0.0017	0.0017	0.0002	8.0999
	Work Boat 1	Two-stroke Outboard (WB)		0.2339	0.2419	0.5431	0.0160	0.0048	0.0048	0.0009	4.1772
Capping (Armor) (12 hours/day)											
	100-ton Crane	Diesel Excavators	Assume each work day contains one 12-hr shift.	0.0224	0.0235	0.1227	0.4218	0.0170	0.0170	0.0011	57.1273
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0105	0.0110	0.0397	0.2205	0.0042	0.0042	0.0005	20.3943
	Work Boat 1	Two-stroke Outboard (WB)		0.5890	0.6090	1.3675	0.0404	0.0121	0.0121	0.0022	10.5176
In situ Treatment (Activated Carbon, Underpier) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0259	0.0273	0.1056	0.1859	0.0165	0.0165	0.0004	19.9174
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0154	0.0162	0.0584	0.3238	0.0062	0.0062	0.0008	29.9508
	Work Boat 1	Two-stroke Outboard (WB)		0.8650	0.8944	2.0083	0.0593	0.0178	0.0178	0.0032	15.4460
Enhanced Natural Recovery (Low Bridge) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0043	0.0045	0.0176	0.0310	0.0027	0.0027	0.0001	3.3177
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0026	0.0027	0.0097	0.0539	0.0010	0.0010	0.0001	4.9891
	Work Boat 1	Two-stroke Outboard (WB)		0.1441	0.1490	0.3345	0.0099	0.0030	0.0030	0.0005	2.5729
			SUBTOTAL EMISSIONS - MATERIAL PLACEMENT	**5.8**	**6.0**	**17**	**23**	**1.1**	**1.1**	**0.08**	**3,648**
LONG-TERM MONITORING (12 hours/day)											
	Work Boat 1	Two-stroke Outboard (WB)	Assume each work day contains one 12 hr-shift. Assume a total of 8 monitoring events based on: a pre-construction baseline sampling, a construction monitoring/confirmational sampling, and long-term monitoring at years 1, 3, 5, 10, 15, and 20.	0.30	0.31	0.69	0.020	0.0062	0.0062	0.0011	5.3
			SUBTOTAL EMISSIONS - LONG-TERM MONITORING	**0.30**	**0.31**	**0.69**	**0.020**	**0.0062**	**0.0062**	**0.0011**	**5.3**
			TOTAL EMISSIONS (metric tons, rounded)	**22**	**23**	**73**	**140**	**5.9**	**5.8**	**0.27**	**16,000**

General Notes:

1. Total emissions for construction equipment/vehicle are calculated as total daily diesel usage (gal/day) / production rate (units/day) x units x emission factor (g/gal) x (1E-6 metric ton/g).
2. Total emissions for rail transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   2a. Total diesel usage for train (gal) is calculated as total tonnage-distance covered (ton-mi) / train fuel economy (ton-mi/gal).
   2b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
3. Total emissions for truck transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   3a. Total diesel usage for trucks (gal) is calculated as total tonnage-distance covered (ton-mi) / truck fuel economy (ton-mi/gal).
   3b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
4. Total emissions for barge transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   4a. Total diesel usage for boats (gal) is calculated as total tonnage-distance covered (ton-mi) / barge fuel economy (ton-mi/gal).
   4b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.

AC = activated carbon; CO = carbon monoxide; CO_2 = carbon dioxide; cy = cubic yard; ENR = enhanced natural recovery; GAC = granular activated carbon; gal = gallon; HP = horse power; na = not applicable; NO_X = nitrogen oxides (NO and NO_2); PB = push boat; $PM_{2.5}$ = particulate matter less that 2.5 microns in diameter; PM_{10} = particulate matter less than 10 microns in diameter; RMC = residuals management cover; SCC = Standard Classification Code; SO_2 = sulfur dioxide; VOC = volatile organic compounds; WB = work boat

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 2B(12) - Total Emissions (tonnes): Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP) 2	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization of 2 derrick rigs and 3 material barges, mob/demob on an annual basis. Assume 8 hrs/day for 35 days per construction season.	0.0737	0.0776	0.2798	1.552	0.02974	0.02974	0.00387	143.6
Pile Removal (12 hrs/day)											
	150-ton Crane 1	Diesel Cranes	Assume each work day contains one 12-hr shift. Assume pile removal occurs at 25 piles/day.	0.0162	0.0170	0.0888	0.3055	0.0123	0.0123	0.0008	41.3718
	Work Boat 1	Two-stroke Outboard (WB)		0.2133	0.2205	0.4952	0.0146	0.0044	0.0044	0.0008	3.8084
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0076	0.0080	0.0288	0.1597	0.0031	0.0031	0.0004	14.7696
			SUBTOTAL EMISSIONS - SITE PREPARATION	**0.3107**	**0.3231**	**0.8926**	**2.0320**	**0.0495**	**0.0495**	**0.0058**	**203.5435**
SEDIMENT REMOVAL											
Open-water Dredging (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.3596	0.3786	1.9735	6.7857	0.2734	0.2734	0.0170	919.0148
	Work Boat 1	Two-stroke Outboard (WB)		8.7460	9.0434	20.3069	0.5995	0.1802	0.1802	0.0320	156.1825
Restricted Access Dredging (Under the West Seattle Bridge) (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Push Boat	Two-stroke Outboard (PB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Work Boat 1	Two-stroke Outboard (WB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydraulic Dredging (Underpiers) (8 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 8-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Push Boat 2	Two-stroke Outboard (PB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Work Boat 2	Two-stroke Outboard (WB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)											
	High-solids Pump	Diesel Pumps	Assume each work day contains one 8-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			SUBTOTAL EMISSIONS - SEDIMENT REMOVAL	**9.1**	**9.4**	**22**	**7**	**0.45**	**0.45**	**0.049**	**1,075**
SEDIMENT TRANSLOADING AND DISPOSAL											
Mechanical Offloading (12 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 12-hr shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way). Assume sediment disposal by rail to landfill in eastern WA for 284 mi (one-way).	0.1552	0.1634	0.6384	3.7236	0.0681	0.0681	0.0088	324.7964
	100-ton Crane	Diesel Cranes		0.6638	0.6990	3.6433	12.5275	0.5047	0.5047	0.0313	1696.6426
	Front-end Loader	Diesel Rough Terrain Forklifts		0.3187	0.3356	1.5454	4.0660	0.3316	0.3316	0.0120	646.1223
	Rail	na		5.1963	5.4717	25.5818	98.9298	3.5974	3.4895	0.0884	9810.3414
			SUBTOTAL EMISSIONS - SEDIMENT TRANSLOADING AND DISPOSAL	**6**	**6.7**	**31**	**119**	**4.5**	**4.4**	**0.14**	**12,478**

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 2B(12) - Total Emissions (tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
CAPPING/TREATMENT MATERIAL PLACEMENT											
Transportation of Materials to EW											
	Dump Truck (20-ton) for sand, gravel, and armor	Diesel Off-highway Trucks	Assume sand, gravel, and armor are transported 20 miles from quarry to shore by truck and 20 miles to the site by barge. Assume activated carbon is transported from Toledo (OH) to site by train for a 2,452 mi distance (one-way).	0.6345	0.6682	3.7913	9.3596	0.6137	0.6137	0.0375	2144.4572
	Tug Boat (3,000 HP) for sand, gravel, and armor	Diesel Inboard/Sterndrive (3,000 HP)		0.1656	0.1743	0.6812	3.9733	0.0727	0.0727	0.0094	346.5789
	Rail for Activated Carbon	na		0.2420	0.2548	1.1914	4.6076	0.1675	0.1625	0.0041	456.9064
Residuals Management Cover, Capping, Backfill, and Enhanced Natural Recovery (Sand) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0963	0.1014	0.5283	1.8166	0.0732	0.0732	0.0045	246.0342
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0451	0.0474	0.1711	0.9495	0.0182	0.0182	0.0024	87.8336
	Work Boat 1	Two-stroke Outboard (WB)		2.5366	2.6228	5.8895	0.1739	0.0523	0.0523	0.0093	45.2968
Capping (Gravel) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0089	0.0093	0.0487	0.1675	0.0067	0.0067	0.0004	22.6889
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0042	0.0044	0.0158	0.0876	0.0017	0.0017	0.0002	8.0999
	Work Boat 1	Two-stroke Outboard (WB)		0.2339	0.2419	0.5431	0.0160	0.0048	0.0048	0.0009	4.1772
Capping (Armor) (12 hours/day)											
	100-ton Crane	Diesel Excavators	Assume each work day contains one 12-hr shift.	0.0224	0.0235	0.1227	0.4218	0.0170	0.0170	0.0011	57.1273
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0105	0.0110	0.0397	0.2205	0.0042	0.0042	0.0005	20.3943
	Work Boat 1	Two-stroke Outboard (WB)		0.5890	0.6090	1.3675	0.0404	0.0121	0.0121	0.0022	10.5176
In situ Treatment (Activated Carbon, Underpier) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0259	0.0273	0.1056	0.1859	0.0165	0.0165	0.0004	19.9174
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0154	0.0162	0.0584	0.3238	0.0062	0.0062	0.0008	29.9508
	Work Boat 1	Two-stroke Outboard (WB)		0.8650	0.8944	2.0083	0.0593	0.0178	0.0178	0.0032	15.4460
Enhanced Natural Recovery (Low Bridge) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0076	0.0080	0.0308	0.0543	0.0048	0.0048	0.0001	5.8170
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0045	0.0047	0.0170	0.0946	0.0018	0.0018	0.0002	8.7473
	Work Boat 1	Two-stroke Outboard (WB)		0.2526	0.2612	0.5865	0.0173	0.0052	0.0052	0.0009	4.5111
			SUBTOTAL EMISSIONS - MATERIAL PLACEMENT	**5.8**	**6.0**	**17**	**23**	**1.1**	**1.1**	**0.08**	**3,535**
LONG-TERM MONITORING (12 hours/day)											
	Work Boat 1	Two-stroke Outboard (WB)	Assume each work day contains one 12 hr-shift. Assume a total of 8 monitoring events based on: a pre-construction baseline sampling, a construction monitoring/confirmational sampling, and long-term monitoring at years 1, 3, 5, 10, 15, and 20.	0.30	0.31	0.69	0.020	0.0062	0.0062	0.0011	5.3
			SUBTOTAL EMISSIONS - LONG-TERM MONITORING	**0.30**	**0.31**	**0.69**	**0.020**	**0.0062**	**0.0062**	**0.0011**	**5.3**
			TOTAL EMISSIONS (metric tons, rounded)	**22**	**23**	**72**	**150**	**6.1**	**6.0**	**0.27**	**17,000**

General Notes:
1. Total emissions for construction equipment/vehicle are calculated as total daily diesel usage (gal/day) / production rate (units/day) x units x emission factor (g/gal) x (1E-6 metric ton/g).
2. Total emissions for rail transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   2a. Total diesel usage for train (gal) is calculated as total tonnage-distance covered (ton-mi) / train fuel economy (ton-mi/gal).
   2b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
3. Total emissions for truck transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   3a. Total diesel usage for trucks (gal) is calculated as total tonnage-distance covered (ton-mi) / truck fuel economy (ton-mi/gal).
   3b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
4. Total emissions for barge transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   4a. Total diesel usage for boats (gal) is calculated as total tonnage-distance covered (ton-mi) / barge fuel economy (ton-mi/gal).
   4b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.

AC = activated carbon; CO = carbon monoxide; CO_2 = carbon dioxide; cy = cubic yard; ENR = enhanced natural recovery; GAC = granular activated carbon; gal = gallon; HP = horse power; na = not applicable; NO_X = nitrogen oxides (NO and NO_2); PB = push boat; $PM_{2.5}$ = particulate matter less that 2.5 microns in diameter; PM_{10} = particulate matter less than 10 microns in diameter; RMC = residuals management cover; SCC = Standard Classification Code; SO_2 = sulfur dioxide; VOC = volatile organic compounds; WB = work boat

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 2C+(12) - Total Emissions (tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP) 2	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization of 2 derrick rigs and 3 material barges, mob/demob on an annual basis. Assume 8 hrs/day for 35 days per construction season.	0.0737	0.0776	0.2798	1.552	0.02974	0.02974	0.00387	143.6
Pile Removal (12 hrs/day)											
	150-ton Crane 1	Diesel Cranes	Assume each work day contains one 12-hr shift. Assume pile removal occurs at 25 piles/day.	0.0162	0.0170	0.0888	0.3055	0.0123	0.0123	0.0008	41.3718
	Work Boat 1	Two-stroke Outboard (WB)		0.2133	0.2205	0.4952	0.0146	0.0044	0.0044	0.0008	3.8084
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0076	0.0080	0.0288	0.1597	0.0031	0.0031	0.0004	14.7696
			SUBTOTAL EMISSIONS - SITE PREPARATION	**0.3107**	**0.3231**	**0.8926**	**2.0320**	**0.0495**	**0.0495**	**0.0058**	**203.5435**
SEDIMENT REMOVAL											
Open-water Dredging (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.3596	0.3786	1.9735	6.7857	0.2734	0.2734	0.0170	919.0148
	Work Boat 1	Two-stroke Outboard (WB)		8.7460	9.0434	20.3069	0.5995	0.1802	0.1802	0.0320	156.1825
Restricted Access Dredging (Under the West Seattle Bridge) (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Push Boat	Two-stroke Outboard (PB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Work Boat 1	Two-stroke Outboard (WB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydraulic Dredging (Underpiers) (8 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 8-hr shift.	0.0306	0.0322	0.1559	0.4337	0.0273	0.0273	0.0016	90.7183
	Push Boat 2	Two-stroke Outboard (PB)		0.6321	0.6536	1.9827	0.0730	0.0125	0.0125	0.0032	15.4892
	Work Boat 2	Two-stroke Outboard (WB)		1.2468	1.2892	2.8950	0.0855	0.0257	0.0257	0.0046	22.2654
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)											
	High-solids Pump	Diesel Pumps	Assume each work day contains one 8-hr shift.	0.1331	0.1402	0.6655	1.2034	0.1206	0.1206	0.0026	137.9580
			SUBTOTAL EMISSIONS - SEDIMENT REMOVAL	**11.1**	**11.5**	**28**	**9**	**0.64**	**0.64**	**0.061**	**1,342**
SEDIMENT TRANSLOADING AND DISPOSAL											
Mechanical Offloading (12 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 12-hr shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way). Assume sediment disposal by rail to landfill in eastern WA for 284 mi (one-way).	0.1564	0.1646	0.6433	3.7526	0.0687	0.0687	0.0089	327.3221
	100-ton Crane	Diesel Cranes		0.6690	0.7044	3.6716	12.6249	0.5086	0.5086	0.0316	1709.8357
	Front-end Loader	Diesel Rough Terrain Forklifts		0.3212	0.3382	1.5574	4.0976	0.3342	0.3342	0.0121	651.1466
	Rail	na		5.2367	5.5143	25.7808	99.6990	3.6254	3.5167	0.0891	9886.6268
			SUBTOTAL EMISSIONS - SEDIMENT TRANSLOADING AND DISPOSAL	**6**	**7**	**32**	**120**	**4.5**	**4.4**	**0.14**	**12,575**

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 2C+(12) - Total Emissions (tonnes)							
				Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
CAPPING/TREATMENT MATERIAL PLACEMENT											
Transportation of Materials to EW											
	Dump Truck (20-ton) for sand, gravel, and armor	Diesel Off-highway Trucks	Assume sand, gravel, and armor are transported 20 miles from quarry to shore by truck and 20 miles to the site by barge. Assume activated carbon is transported from Toledo (OH) to site by train for a 2,452 mi distance (one-way).	0.6344	0.6680	3.7904	9.3574	0.6135	0.6135	0.0375	2143.9541
	Tug Boat (3,000 HP) for sand, gravel, and armor	Diesel Inboard/Sterndrive (3,000 HP)		0.1655	0.1743	0.6810	3.9724	0.0727	0.0727	0.0094	346.4976
	Rail for Activated Carbon	na		0.2420	0.2548	1.1914	4.6076	0.1675	0.1625	0.0041	456.9066
Residuals Management Cover, Capping, Backfill, and Enhanced Natural Recovery (Sand) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0962	0.1013	0.5282	1.8161	0.0732	0.0732	0.0045	245.9652
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0450	0.0474	0.1711	0.9492	0.0182	0.0182	0.0024	87.8090
	Work Boat 1	Two-stroke Outboard (WB)		2.5358	2.6221	5.8879	0.1738	0.0522	0.0522	0.0093	45.2841
Capping (Gravel) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0089	0.0093	0.0487	0.1675	0.0067	0.0067	0.0004	22.6889
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0042	0.0044	0.0158	0.0876	0.0017	0.0017	0.0002	8.0999
	Work Boat 1	Two-stroke Outboard (WB)		0.2339	0.2419	0.5431	0.0160	0.0048	0.0048	0.0009	4.1772
Capping (Armor) (12 hours/day)											
	100-ton Crane	Diesel Excavators	Assume each work day contains one 12-hr shift.	0.0224	0.0235	0.1227	0.4218	0.0170	0.0170	0.0011	57.1273
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0105	0.0110	0.0397	0.2205	0.0042	0.0042	0.0005	20.3943
	Work Boat 1	Two-stroke Outboard (WB)		0.5890	0.6090	1.3675	0.0404	0.0121	0.0121	0.0022	10.5176
In situ Treatment (Activated Carbon, Underpier) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0259	0.0273	0.1056	0.1859	0.0165	0.0165	0.0004	19.9174
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0154	0.0162	0.0584	0.3238	0.0062	0.0062	0.0008	29.9508
	Work Boat 1	Two-stroke Outboard (WB)		0.8650	0.8944	2.0083	0.0593	0.0178	0.0178	0.0032	15.4460
Enhanced Natural Recovery (Low Bridge) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0076	0.0080	0.0308	0.0543	0.0048	0.0048	0.0001	5.8170
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0045	0.0047	0.0170	0.0946	0.0018	0.0018	0.0002	8.7473
	Work Boat 1	Two-stroke Outboard (WB)		0.2526	0.2612	0.5865	0.0173	0.0052	0.0052	0.0009	4.5111
			SUBTOTAL EMISSIONS - MATERIAL PLACEMENT	**5.8**	**6.0**	**17**	**23**	**1.1**	**1.1**	**0.08**	**3,534**
LONG-TERM MONITORING (12 hours/day)											
	Work Boat 1	Two-stroke Outboard (WB)	Assume each work day contains one 12 hr-shift. Assume a total of 8 monitoring events based on: a pre-construction baseline sampling, a construction monitoring/confirmational sampling, and long-term monitoring at years 1, 3, 5, 10, 15, and 20.	0.30	0.31	0.69	0.020	0.0062	0.0062	0.0011	5.3
			SUBTOTAL EMISSIONS - LONG-TERM MONITORING	**0.30**	**0.31**	**0.69**	**0.020**	**0.0062**	**0.0062**	**0.0011**	**5.3**
			TOTAL EMISSIONS (metric tons, rounded)	**24**	**25**	**78**	**150**	**6.3**	**6.2**	**0.29**	**18,000**

General Notes:

1. Total emissions for construction equipment/vehicle are calculated as total daily diesel usage (gal/day) / production rate (units/day) x units x emission factor (g/gal) x (1E-6 metric ton/g).
2. Total emissions for rail transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   2a. Total diesel usage for train (gal) is calculated as total tonnage-distance covered (ton-mi) / train fuel economy (ton-mi/gal).
   2b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
3. Total emissions for truck transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   3a. Total diesel usage for trucks (gal) is calculated as total tonnage-distance covered (ton-mi) / truck fuel economy (ton-mi/gal).
   3b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
4. Total emissions for barge transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   4a. Total diesel usage for boats (gal) is calculated as total tonnage-distance covered (ton-mi) / barge fuel economy (ton-mi/gal).
   4b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.

AC = activated carbon; CO = carbon monoxide; CO_2 = carbon dioxide; cy = cubic yard; ENR = enhanced natural recovery; GAC = granular activated carbon; gal = gallon; HP = horse power; na = not applicable; NO_X = nitrogen oxides (NO and NO_2); PB = push boat; $PM_{2.5}$ = particulate matter less that 2.5 microns in diameter; PM_{10} = particulate matter less than 10 microns in diameter; RMC = residuals management cover; SCC = Standard Classification Code; SO_2 = sulfur dioxide; VOC = volatile organic compounds; WB = work boat

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 3B(12) - Total Emissions (tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP) 2	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization of 2 derrick rigs and 3 material barges, mob/demob on an annual basis. Assume 8 hrs/day for 35 days per construction season.	0.0737	0.0776	0.2798	1.552	0.02974	0.02974	0.00387	143.6
Pile Removal (12 hrs/day)											
	150-ton Crane 1	Diesel Cranes	Assume each work day contains one 12-hr shift. Assume pile removal occurs at 25 piles/day.	0.0162	0.0170	0.0888	0.3055	0.0123	0.0123	0.0008	41.3718
	Work Boat 1	Two-stroke Outboard (WB)		0.2133	0.2205	0.4952	0.0146	0.0044	0.0044	0.0008	3.8084
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0076	0.0080	0.0288	0.1597	0.0031	0.0031	0.0004	14.7696
			SUBTOTAL EMISSIONS - SITE PREPARATION	**0.3107**	**0.3231**	**0.8926**	**2.0320**	**0.0495**	**0.0495**	**0.0058**	**203.5435**
SEDIMENT REMOVAL											
Open-water Dredging (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.3740	0.3938	2.0527	7.0583	0.2844	0.2844	0.0177	955.9320
	Work Boat 1	Two-stroke Outboard (WB)		9.0973	9.4066	21.1227	0.6236	0.1874	0.1874	0.0333	162.4565
Restricted Access Dredging (Under the West Seattle Bridge) (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0270	0.0285	0.1484	0.5102	0.0206	0.0206	0.0013	69.1013
	Push Boat	Two-stroke Outboard (PB)		0.3334	0.3447	1.0457	0.0385	0.0066	0.0066	0.0017	8.1695
	Work Boat 1	Two-stroke Outboard (WB)		0.6576	0.6800	1.5269	0.0451	0.0135	0.0135	0.0024	11.7435
Hydraulic Dredging (Underpiers) (8 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 8-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Push Boat 2	Two-stroke Outboard (PB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Work Boat 2	Two-stroke Outboard (WB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)											
	High-solids Pump	Diesel Pumps	Assume each work day contains one 8-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			SUBTOTAL EMISSIONS - SEDIMENT REMOVAL	**10.5**	**10.9**	**26**	**8**	**0.51**	**0.51**	**0.056**	**1,207**
SEDIMENT TRANSLOADING AND DISPOSAL											
Mechanical Offloading (12 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 12-hr shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way). Assume sediment disposal by rail to landfill in eastern WA for 284 mi (one-way).	0.1642	0.1730	0.6758	3.9419	0.0721	0.0721	0.0093	343.8381
	100-ton Crane	Diesel Cranes		0.7027	0.7400	3.8569	13.2620	0.5343	0.5343	0.0332	1796.1106
	Front-end Loader	Diesel Rough Terrain Forklifts		0.3374	0.3553	1.6360	4.3044	0.3510	0.3510	0.0127	684.0021
	Rail	na		5.5010	5.7925	27.0816	104.7296	3.8084	3.6941	0.0936	10385.4860
			SUBTOTAL EMISSIONS - SEDIMENT TRANSLOADING AND DISPOSAL	**7**	**7**	**33**	**126**	**4.8**	**4.7**	**0.15**	**13,209**

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 3B(12) - Total Emissions (tonnes)							
				Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
CAPPING/TREATMENT MATERIAL PLACEMENT											
Transportation of Materials to EW											
	Dump Truck (20-ton) for sand, gravel, and armor	Diesel Off-highway Trucks	Assume sand, gravel, and armor are transported 20 miles from quarry to shore by truck and 20 miles to the site by barge. Assume activated carbon is transported from Toledo (OH) to site by train for a 2,452 mi distance (one-way).	0.6043	0.6363	3.6105	8.9133	0.5844	0.5844	0.0357	2042.2047
	Tug Boat (3,000 HP) for sand, gravel, and armor	Diesel Inboard/Sterndrive (3,000 HP)		0.1577	0.1660	0.6487	3.7839	0.0693	0.0693	0.0089	330.0533
	Rail for Activated Carbon	na		0.2420	0.2548	1.1914	4.6076	0.1675	0.1625	0.0041	456.9064
Residuals Management Cover, Capping, Backfill, and Enhanced Natural Recovery (Sand) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0989	0.1041	0.5426	1.8659	0.0752	0.0752	0.0047	252.6989
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0463	0.0487	0.1758	0.9752	0.0187	0.0187	0.0024	90.2129
	Work Boat 1	Two-stroke Outboard (WB)		2.6053	2.6938	6.0491	0.1786	0.0537	0.0537	0.0095	46.5238
Capping (Gravel) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0051	0.0053	0.0278	0.0956	0.0039	0.0039	0.0002	12.9500
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0024	0.0025	0.0090	0.0500	0.0010	0.0010	0.0001	4.6231
	Work Boat 1	Two-stroke Outboard (WB)		0.1335	0.1381	0.3100	0.0092	0.0028	0.0028	0.0005	2.3842
Capping (Armor) (12 hours/day)											
	100-ton Crane	Diesel Excavators	Assume each work day contains one 12-hr shift.	0.0128	0.0134	0.0700	0.2408	0.0097	0.0097	0.0006	32.6062
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0060	0.0063	0.0227	0.1258	0.0024	0.0024	0.0003	11.6403
	Work Boat 1	Two-stroke Outboard (WB)		0.3362	0.3476	0.7805	0.0230	0.0069	0.0069	0.0012	6.0031
In situ Treatment (Activated Carbon, Underpier) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0259	0.0273	0.1056	0.1859	0.0165	0.0165	0.0004	19.9174
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0154	0.0162	0.0584	0.3238	0.0062	0.0062	0.0008	29.9508
	Work Boat 1	Two-stroke Outboard (WB)		0.8650	0.8944	2.0083	0.0593	0.0178	0.0178	0.0032	15.4460
Enhanced Natural Recovery (Low Bridge) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0076	0.0080	0.0308	0.0543	0.0048	0.0048	0.0001	5.8170
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0045	0.0047	0.0170	0.0946	0.0018	0.0018	0.0002	8.7473
	Work Boat 1	Two-stroke Outboard (WB)		0.2526	0.2612	0.5865	0.0173	0.0052	0.0052	0.0009	4.5111
			SUBTOTAL EMISSIONS - MATERIAL PLACEMENT	**5.4**	**5.6**	**16**	**22**	**1.0**	**1.0**	**0.07**	**3,373**
***LONG-TERM MONITORING* (12 hours/day)**											
	Work Boat 1	Two-stroke Outboard (WB)	Assume each work day contains one 12 hr-shift. Assume a total of 8 monitoring events based on: a pre-construction baseline sampling, a construction monitoring/confirmational sampling, and long-term monitoring at years 1, 3, 5, 10, 15, and 20.	0.30	0.31	0.69	0.020	0.0062	0.0062	0.0011	5.3
			SUBTOTAL EMISSIONS - LONG-TERM MONITORING	**0.30**	**0.31**	**0.69**	**0.020**	**0.0062**	**0.0062**	**0.0011**	**5.3**
			TOTAL EMISSIONS (metric tons, rounded)	**23**	**24**	**77**	**160**	**6.4**	**6.3**	**0.29**	**18,000**

General Notes:

1. Total emissions for construction equipment/vehicle are calculated as total daily diesel usage (gal/day) / production rate (units/day) x units x emission factor (g/gal) x (1E-6 metric ton/g).
2. Total emissions for rail transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   2a. Total diesel usage for train (gal) is calculated as total tonnage-distance covered (ton-mi) / train fuel economy (ton-mi/gal).
   2b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
3. Total emissions for truck transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   3a. Total diesel usage for trucks (gal) is calculated as total tonnage-distance covered (ton-mi) / truck fuel economy (ton-mi/gal).
   3b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
4. Total emissions for barge transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   4a. Total diesel usage for boats (gal) is calculated as total tonnage-distance covered (ton-mi) / barge fuel economy (ton-mi/gal).
   4b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.

AC = activated carbon; CO = carbon monoxide; CO_2 = carbon dioxide; cy = cubic yard; ENR = enhanced natural recovery; GAC = granular activated carbon; gal = gallon; HP = horse power; na = not applicable; NO_X = nitrogen oxides (NO and NO_2); PB = push boat; $PM_{2.5}$ = particulate matter less that 2.5 microns in diameter; PM_{10} = particulate matter less than 10 microns in diameter; RMC = residuals management cover; SCC = Standard Classification Code; SO_2 = sulfur dioxide; VOC = volatile organic compounds; WB = work boat

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 3C+(12) - Total Emissions (tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP) 2	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization of 2 derrick rigs and 3 material barges, mob/demob on an annual basis. Assume 8 hrs/day for 35 days per construction season.	0.0737	0.0776	0.2798	1.552	0.02974	0.02974	0.00387	143.6
Pile Removal (12 hrs/day)											
	150-ton Crane 1	Diesel Cranes	Assume each work day contains one 12-hr shift. Assume pile removal occurs at 25 piles/day.	0.0162	0.0170	0.0888	0.3055	0.0123	0.0123	0.0008	41.3718
	Work Boat 1	Two-stroke Outboard (WB)		0.2133	0.2205	0.4952	0.0146	0.0044	0.0044	0.0008	3.8084
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0076	0.0080	0.0288	0.1597	0.0031	0.0031	0.0004	14.7696
			SUBTOTAL EMISSIONS - SITE PREPARATION	**0.3107**	**0.3231**	**0.8926**	**2.0320**	**0.0495**	**0.0495**	**0.0058**	**203.5435**
SEDIMENT REMOVAL											
Open-water Dredging (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.3740	0.3938	2.0527	7.0583	0.2844	0.2844	0.0177	955.9320
	Work Boat 1	Two-stroke Outboard (WB)		9.0973	9.4066	21.1227	0.6236	0.1874	0.1874	0.0333	162.4565
Restricted Access Dredging (Under the West Seattle Bridge) (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0270	0.0285	0.1484	0.5102	0.0206	0.0206	0.0013	69.1013
	Push Boat	Two-stroke Outboard (PB)		0.3334	0.3447	1.0457	0.0385	0.0066	0.0066	0.0017	8.1695
	Work Boat 1	Two-stroke Outboard (WB)		0.6576	0.6800	1.5269	0.0451	0.0135	0.0135	0.0024	11.7435
Hydraulic Dredging (Underpiers) (8 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 8-hr shift.	0.0306	0.0322	0.1559	0.4337	0.0273	0.0273	0.0016	90.7183
	Push Boat 2	Two-stroke Outboard (PB)		0.6321	0.6536	1.9827	0.0730	0.0125	0.0125	0.0032	15.4892
	Work Boat 2	Two-stroke Outboard (WB)		1.2468	1.2892	2.8950	0.0855	0.0257	0.0257	0.0046	22.2654
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)											
	High-solids Pump	Diesel Pumps	Assume each work day contains one 8-hr shift.	0.1331	0.1402	0.6655	1.2034	0.1206	0.1206	0.0026	137.9580
			SUBTOTAL EMISSIONS - SEDIMENT REMOVAL	**12.5**	**13.0**	**32**	**10**	**0.70**	**0.70**	**0.068**	**1,474**
SEDIMENT TRANSLOADING AND DISPOSAL											
Mechanical Offloading (12 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 12-hr shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way). Assume sediment disposal by rail to landfill in eastern WA for 284 mi (one-way).	0.1655	0.1742	0.6808	3.9709	0.0727	0.0727	0.0094	346.3637
	100-ton Crane	Diesel Cranes		0.7079	0.7454	3.8852	13.3594	0.5382	0.5382	0.0334	1809.3037
	Front-end Loader	Diesel Rough Terrain Forklifts		0.3399	0.3579	1.6481	4.3360	0.3536	0.3536	0.0128	689.0264
	Rail	na		5.5414	5.8350	27.2805	105.4989	3.8363	3.7212	0.0943	10461.7714
			SUBTOTAL EMISSIONS - SEDIMENT TRANSLOADING AND DISPOSAL	**7**	**7**	**33**	**127**	**4.8**	**4.7**	**0.15**	**13,306**

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 3C+(12) - Total Emissions (tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
CAPPING/TREATMENT MATERIAL PLACEMENT											
Transportation of Materials to EW											
	Dump Truck (20-ton) for sand, gravel, and armor	Diesel Off-highway Trucks	Assume sand, gravel, and armor are transported 20 miles from quarry to shore by truck and 20 miles to the site by barge. Assume activated carbon is transported from Toledo (OH) to site by train for a 2,452 mi distance (one-way).	0.6035	0.6355	3.6060	8.9020	0.5837	0.5837	0.0357	2039.6140
	Tug Boat (3,000 HP) for sand, gravel, and armor	Diesel Inboard/Sterndrive (3,000 HP)		0.1575	0.1658	0.6479	3.7791	0.0692	0.0692	0.0089	329.6346
	Rail for Activated Carbon	na		0.2420	0.2548	1.1914	4.6076	0.1675	0.1625	0.0041	456.9066
Residuals Management Cover, Capping, Backfill, and Enhanced Natural Recovery (Sand) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0987	0.1040	0.5419	1.8632	0.0751	0.0751	0.0047	252.3435
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0462	0.0487	0.1755	0.9738	0.0187	0.0187	0.0024	90.0860
	Work Boat 1	Two-stroke Outboard (WB)		2.6016	2.6901	6.0405	0.1783	0.0536	0.0536	0.0095	46.4584
Capping (Gravel) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0051	0.0053	0.0278	0.0956	0.0039	0.0039	0.0002	12.9500
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0024	0.0025	0.0090	0.0500	0.0010	0.0010	0.0001	4.6231
	Work Boat 1	Two-stroke Outboard (WB)		0.1335	0.1381	0.3100	0.0092	0.0028	0.0028	0.0005	2.3842
Capping (Armor) (12 hours/day)											
	100-ton Crane	Diesel Excavators	Assume each work day contains one 12-hr shift.	0.0128	0.0134	0.0700	0.2408	0.0097	0.0097	0.0006	32.6062
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0060	0.0063	0.0227	0.1258	0.0024	0.0024	0.0003	11.6403
	Work Boat 1	Two-stroke Outboard (WB)		0.3362	0.3476	0.7805	0.0230	0.0069	0.0069	0.0012	6.0031
In situ Treatment (Activated Carbon, Underpier) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0259	0.0273	0.1056	0.1859	0.0165	0.0165	0.0004	19.9174
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0154	0.0162	0.0584	0.3238	0.0062	0.0062	0.0008	29.9508
	Work Boat 1	Two-stroke Outboard (WB)		0.8650	0.8944	2.0083	0.0593	0.0178	0.0178	0.0032	15.4460
Enhanced Natural Recovery (Low Bridge) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0076	0.0080	0.0308	0.0543	0.0048	0.0048	0.0001	5.8170
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0045	0.0047	0.0170	0.0946	0.0018	0.0018	0.0002	8.7473
	Work Boat 1	Two-stroke Outboard (WB)		0.2526	0.2612	0.5865	0.0173	0.0052	0.0052	0.0009	4.5111
			SUBTOTAL EMISSIONS - MATERIAL PLACEMENT	**5.4**	**5.6**	**16**	**22**	**1.0**	**1.0**	**0.07**	**3,370**
LONG-TERM MONITORING **(12 hours/day)**											
	Work Boat 1	Two-stroke Outboard (WB)	Assume each work day contains one 12 hr-shift. Assume a total of 8 monitoring events based on: a pre-construction baseline sampling, a construction monitoring/confirmational sampling, and long-term monitoring at years 1, 3, 5, 10, 15, and 20.	0.30	0.31	0.69	0.020	0.0062	0.0062	0.0011	5.3
			SUBTOTAL EMISSIONS - LONG-TERM MONITORING	**0.30**	**0.31**	**0.69**	**0.020**	**0.0062**	**0.0062**	**0.0011**	**5.3**
			TOTAL EMISSIONS (metric tons, rounded)	**25**	**26**	**83**	**160**	**6.6**	**6.5**	**0.30**	**18,000**

General Notes:

1. Total emissions for construction equipment/vehicle are calculated as total daily diesel usage (gal/day) / production rate (units/day) x units x emission factor (g/gal) x (1E-6 metric ton/g).
2. Total emissions for rail transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   2a. Total diesel usage for train (gal) is calculated as total tonnage-distance covered (ton-mi) / train fuel economy (ton-mi/gal).
   2b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
3. Total emissions for truck transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   3a. Total diesel usage for trucks (gal) is calculated as total tonnage-distance covered (ton-mi) / truck fuel economy (ton-mi/gal).
   3b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
4. Total emissions for barge transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   4a. Total diesel usage for boats (gal) is calculated as total tonnage-distance covered (ton-mi) / barge fuel economy (ton-mi/gal).
   4b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.

AC = activated carbon; CO = carbon monoxide; CO_2 = carbon dioxide; cy = cubic yard; ENR = enhanced natural recovery; GAC = granular activated carbon; gal = gallon; HP = horse power; na = not applicable; NO_X = nitrogen oxides (NO and NO_2); PB = push boat; $PM_{2.5}$ = particulate matter less that 2.5 microns in diameter; PM_{10} = particulate matter less than 10 microns in diameter; RMC = residuals management cover; SCC = Standard Classification Code; SO_2 = sulfur dioxide; VOC = volatile organic compounds; WB = work boat

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
				Alternative 2C+(7.5) - Total Emissions (tonnes)							
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP) 2	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization of 2 derrick rigs and 3 material barges, mob/demob on an annual basis. Assume 8 hrs/day for 35 days per construction season.	0.0810	0.0853	0.3078	1.707	0.03271	0.03271	0.00426	158.0
Pile Removal (12 hrs/day)											
	150-ton Crane 1	Diesel Cranes	Assume each work day contains one 12-hr shift. Assume pile removal occurs at 25 piles/day.	0.0162	0.0170	0.0888	0.3055	0.0123	0.0123	0.0008	41.3718
	Work Boat 1	Two-stroke Outboard (WB)		0.2133	0.2205	0.4952	0.0146	0.0044	0.0044	0.0008	3.8084
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0076	0.0080	0.0288	0.1597	0.0031	0.0031	0.0004	14.7696
			SUBTOTAL EMISSIONS - SITE PREPARATION	**0.3181**	**0.3309**	**0.9206**	**2.1872**	**0.0525**	**0.0525**	**0.0062**	**218**
SEDIMENT REMOVAL											
Open-water Dredging (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.4017	0.4230	2.2046	7.5806	0.3054	0.3054	0.0190	1026.6628
	Work Boat 1	Two-stroke Outboard (WB)		9.7704	10.1026	22.6856	0.6697	0.2013	0.2013	0.0358	174.4769
Restricted Access Dredging (Under the West Seattle Bridge) (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Push Boat	Two-stroke Outboard (PB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Work Boat 1	Two-stroke Outboard (WB)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydraulic Dredging (Underpiers) (8 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 8-hr shift.	0.0306	0.0322	0.1559	0.4337	0.0273	0.0273	0.0016	90.7183
	Push Boat 2	Two-stroke Outboard (PB)		0.6321	0.6536	1.9827	0.0730	0.0125	0.0125	0.0032	15.4892
	Work Boat 2	Two-stroke Outboard (WB)		1.2468	1.2892	2.8950	0.0855	0.0257	0.0257	0.0046	22.2654
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)											
	High-solids Pump	Diesel Pumps	Assume each work day contains one 8-hr shift.	0.1331	0.1402	0.6655	1.2034	0.1206	0.1206	0.0026	137.9580
			SUBTOTAL EMISSIONS - SEDIMENT REMOVAL	**12.2**	**12.6**	**30.6**	**10.0**	**0.7**	**0.7**	**0.1**	**1467.6**
SEDIMENT TRANSLOADING AND DISPOSAL											
Mechanical Offloading (12 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 12-hr shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way). Assume sediment disposal by rail to landfill in eastern WA for 284 mi (one-way).	0.1745	0.1838	0.7181	4.1887	0.0767	0.0767	0.0099	365.3668
	100-ton Crane	Diesel Cranes		0.7467	0.7863	4.0984	14.0924	0.5677	0.5677	0.0353	1908.5706
	Front-end Loader	Diesel Rough Terrain Forklifts		0.3585	0.3775	1.7385	4.5739	0.3730	0.3730	0.0135	726.8296
	Rail	na		5.8454	6.1552	28.7773	111.2871	4.0468	3.9254	0.0994	11035.7530
			SUBTOTAL EMISSIONS - SEDIMENT TRANSLOADING AND DISPOSAL	**7.1**	**7.5**	**35.3**	**134.1**	**5.1**	**4.9**	**0.2**	**14036.5**

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 2C+(7.5) - Total Emissions (tonnes): Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
CAPPING/TREATMENT MATERIAL PLACEMENT											
Transportation of Materials to EW											
	Dump Truck (20-ton) for sand, gravel, and armor	Diesel Off-highway Trucks	Assume sand, gravel, and armor are transported 20 miles from quarry to shore by truck and 20 miles to the site by barge. Assume activated carbon is transported from Toledo (OH) to site by train for a 2,452 mi distance (one-way).	0.656	0.691	3.919	9.675	0.634	0.634	0.039	2216.761
	Tug Boat (3,000 HP) for sand, gravel, and armor	Diesel Inboard/Sterndrive (3,000 HP)		0.171	0.180	0.704	4.107	0.075	0.075	0.010	358.264
	Rail for Activated Carbon	na		0.254	0.268	1.252	4.841	0.176	0.171	0.004	480.042
Residuals Management Cover, Capping, Backfill, and Enhanced Natural Recovery (Sand) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.100	0.105	0.549	1.888	0.076	0.076	0.005	255.750
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.047	0.049	0.178	0.987	0.019	0.019	0.002	91.302
	Work Boat 1	Two-stroke Outboard (WB)		2.637	2.726	6.122	0.181	0.054	0.054	0.010	47.086
Capping (Gravel) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.009	0.009	0.049	0.168	0.007	0.007	0.000	22.785
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.004	0.004	0.016	0.088	0.002	0.002	0.000	8.134
	Work Boat 1	Two-stroke Outboard (WB)		0.235	0.243	0.545	0.016	0.005	0.005	0.001	4.195
Capping (Armor) (12 hours/day)											
	100-ton Crane	Diesel Excavators	Assume each work day contains one 12-hr shift.	0.022	0.024	0.123	0.424	0.017	0.017	0.001	57.370
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.011	0.011	0.040	0.221	0.004	0.004	0.001	20.481
	Work Boat 1	Two-stroke Outboard (WB)		0.591	0.612	1.373	0.041	0.012	0.012	0.002	10.562
In situ Treatment (Activated Carbon, Underpier) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.027	0.029	0.111	0.195	0.017	0.017	0.000	20.926
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.016	0.017	0.061	0.340	0.007	0.007	0.001	31.467
	Work Boat 1	Two-stroke Outboard (WB)		0.909	0.940	2.110	0.062	0.019	0.019	0.003	16.228
Enhanced Natural Recovery (Low Bridge) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.008	0.009	0.034	0.060	0.005	0.005	0.000	6.391
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.005	0.005	0.019	0.104	0.002	0.002	0.000	9.610
	Work Boat 1	Two-stroke Outboard (WB)		0.278	0.287	0.644	0.019	0.006	0.006	0.001	4.956
			SUBTOTAL EMISSIONS - MATERIAL PLACEMENT	**6.0**	**6.2**	**18**	**23**	**1.1**	**1.1**	**0.08**	**3,662**
LONG-TERM MONITORING (12 hours/day)											
	Work Boat 1	Two-stroke Outboard (WB)	Assume each work day contains one 12 hr-shift. Assume a total of 8 monitoring events based on: a pre-construction baseline sampling, a construction monitoring/confirmational sampling, and long-term monitoring at years 1, 3, 5, 10, 15, and 20.	0.30	0.31	0.69	0.020	0.0062	0.0062	0.0011	5.3
			SUBTOTAL EMISSIONS - LONG-TERM MONITORING	**0.30**	**0.31**	**0.69**	**0.020**	**0.0062**	**0.0062**	**0.0011**	**5.3**
			TOTAL EMISSIONS (metric tons, rounded)	**26**	**27**	**85**	**170**	**7.00**	**6.80**	**0.31**	**19,000**

General Notes:
1. Total emissions for construction equipment/vehicle are calculated as total daily diesel usage (gal/day) / production rate (units/day) x units x emission factor (g/gal) x (1E-6 metric ton/g).
2. Total emissions for rail transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   2a. Total diesel usage for train (gal) is calculated as total tonnage-distance covered (ton-mi) / train fuel economy (ton-mi/gal).
   2b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
3. Total emissions for truck transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   3a. Total diesel usage for trucks (gal) is calculated as total tonnage-distance covered (ton-mi) / truck fuel economy (ton-mi/gal).
   3b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
4. Total emissions for barge transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   4a. Total diesel usage for boats (gal) is calculated as total tonnage-distance covered (ton-mi) / barge fuel economy (ton-mi/gal).
   4b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.

AC = activated carbon; CO = carbon monoxide; CO_2 = carbon dioxide; cy = cubic yard; ENR = enhanced natural recovery; GAC = granular activated carbon; gal = gallon; HP = horse power; na = not applicable; NO_X = nitrogen oxides (NO and NO_2); PB = push boat; $PM_{2.5}$ = particulate matter less that 2.5 microns in diameter; PM_{10} = particulate matter less than 10 microns in diameter; RMC = residuals management cover; SCC = Standard Classification Code; SO_2 = sulfur dioxide; VOC = volatile organic compounds; WB = work boat

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 3E(7.5) - Total Emissions (tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP) 2	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization of 2 derrick rigs and 3 material barges, mob/demob on an annual basis. Assume 8 hrs/day for 35 days per construction season.	0.0958	0.1008	0.3637	2.0179	0.0387	0.0387	0.0050	186.6718
Pile Removal (12 hrs/day)											
	150-ton Crane 1	Diesel Cranes	Assume each work day contains one 12-hr shift. Assume pile removal occurs at 25 piles/day.	0.0162	0.0170	0.0888	0.3055	0.0123	0.0123	0.0008	41.3718
	Work Boat 1	Two-stroke Outboard (WB)		0.2133	0.2205	0.4952	0.0146	0.0044	0.0044	0.0008	3.8084
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0076	0.0080	0.0288	0.1597	0.0031	0.0031	0.0004	14.7696
			SUBTOTAL EMISSIONS - SITE PREPARATION	**0.3328**	**0.3464**	**0.9765**	**2.4977**	**0.0584**	**0.0584**	**0.0070**	**247**
SEDIMENT REMOVAL											
Open-water Dredging (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.4051	0.4266	2.2233	7.6450	0.3080	0.3080	0.0191	1035.3832
	Work Boat 1	Two-stroke Outboard (WB)		9.8534	10.1884	22.8783	0.6754	0.2030	0.2030	0.0361	175.9588
Restricted Access Dredging (Under the West Seattle Bridge) (12 hours/day)											
	Derrick Rig	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0314	0.0331	0.1726	0.5934	0.0239	0.0239	0.0015	80.3629
	Push Boat	Two-stroke Outboard (PB)		0.3877	0.4009	1.2162	0.0448	0.0077	0.0077	0.0020	9.5008
	Work Boat 1	Two-stroke Outboard (WB)		0.7648	0.7908	1.7757	0.0524	0.0158	0.0158	0.0028	13.6573
Hydraulic Dredging (Underpiers) (8 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 8-hr shift.	0.2014	0.2120	1.0269	2.8571	0.1797	0.1797	0.0105	597.6081
	Push Boat 2	Two-stroke Outboard (PB)		4.1637	4.3053	13.0612	0.4809	0.0823	0.0823	0.0209	102.0351
	Work Boat 2	Two-stroke Outboard (WB)		8.2135	8.4928	19.0706	0.5630	0.1692	0.1692	0.0301	146.6739
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)											
	High-solids Pump	Diesel Pumps	Assume each work day contains one 8-hr shift.	0.8771	0.9235	4.3839	7.9272	0.7948	0.7948	0.0173	908.8004
			SUBTOTAL EMISSIONS - SEDIMENT REMOVAL	**24.8982**	**25.7735**	**65.8086**	**20.8391**	**1.7842**	**1.7842**	**0.1403**	**3070**
SEDIMENT TRANSLOADING AND DISPOSAL											
Mechanical Offloading (12 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 12-hr shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way). Assume sediment disposal by rail to landfill in eastern WA for 284 mi (one-way).	0.1861	0.1959	0.7656	4.4658	0.0817	0.0817	0.0106	389.5321
	100-ton Crane	Diesel Cranes		0.7961	0.8383	4.3695	15.0244	0.6053	0.6053	0.0376	2034.8028
	Front-end Loader	Diesel Rough Terrain Forklifts		0.3822	0.4025	1.8535	4.8764	0.3977	0.3977	0.0144	774.9019
	Rail	na		6.2320	6.5623	30.6806	118.6476	4.3145	4.1850	0.1060	11765.6541
			SUBTOTAL EMISSIONS - SEDIMENT TRANSLOADING AND DISPOSAL	**7.5964**	**7.9990**	**37.6691**	**143.0142**	**5.3992**	**5.2697**	**0.1686**	**14965**

Table 9. Detailed Summary of Direct Emissions By Activity and Alternative

Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Alternative 3E(7.5) - Total Emissions (tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
CAPPING/TREATMENT MATERIAL PLACEMENT											
Transportation of Materials to EW											
	Dump Truck (20-ton) for sand, gravel, and armor	Diesel Off-highway Trucks	Assume sand, gravel, and armor are transported 20 miles from quarry to shore by truck and 20 miles to the site by barge. Assume activated carbon is transported from Toledo (OH) to site by train for a 2,452 mi distance (one-way).	0.6239	0.6569	3.7274	9.2019	0.6033	0.6033	0.0369	2108.3287
	Tug Boat (3,000 HP) for sand, gravel, and armor	Diesel Inboard/Sterndrive (3,000 HP)		0.1628	0.1714	0.6697	3.9064	0.0715	0.0715	0.0092	340.7400
	Rail for Activated Carbon	na		0.2543	0.2677	1.2518	4.8409	0.1760	0.1708	0.0043	480.0451
Residuals Management Cover, Capping, Backfill, and Enhanced Natural Recovery (Sand) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.1023	0.1078	0.5617	1.9313	0.0778	0.0778	0.0048	261.5665
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0479	0.0504	0.1819	1.0094	0.0193	0.0193	0.0025	93.3786
	Work Boat 1	Two-stroke Outboard (WB)		2.6967	2.7884	6.2613	0.1848	0.0556	0.0556	0.0099	48.1564
Capping (Gravel) (12 hours/day)											
	100-ton Crane	Diesel Cranes	Assume each work day contains one 12-hr shift.	0.0051	0.0054	0.0280	0.0963	0.0039	0.0039	0.0002	13.0467
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0024	0.0025	0.0091	0.0503	0.0010	0.0010	0.0001	4.6576
	Work Boat 1	Two-stroke Outboard (WB)		0.1345	0.1391	0.3123	0.0092	0.0028	0.0028	0.0005	2.4020
Capping (Armor) (12 hours/day)											
	100-ton Crane	Diesel Excavators	Assume each work day contains one 12-hr shift.	0.0129	0.0135	0.0705	0.2426	0.0098	0.0098	0.0006	32.8498
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0060	0.0063	0.0228	0.1268	0.0024	0.0024	0.0003	11.7273
	Work Boat 1	Two-stroke Outboard (WB)		0.3387	0.3502	0.7864	0.0232	0.0070	0.0070	0.0012	6.0479
In situ Treatment (Activated Carbon, Underpier) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0272	0.0287	0.1109	0.1953	0.0173	0.0173	0.0004	20.9261
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0161	0.0170	0.0613	0.3402	0.0065	0.0065	0.0008	31.4676
	Work Boat 1	Two-stroke Outboard (WB)		0.9088	0.9397	2.1100	0.0623	0.0187	0.0187	0.0033	16.2282
Enhanced Natural Recovery (Low Bridge) (12 hours/day)											
	Telebelt	Diesel Other Material Handling Equip.	Assume each work day contains one 12-hr shift.	0.0083	0.0088	0.0339	0.0597	0.0053	0.0053	0.0001	6.3908
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)		0.0049	0.0052	0.0187	0.1039	0.0020	0.0020	0.0003	9.6102
	Work Boat 1	Two-stroke Outboard (WB)		0.2775	0.2870	0.6444	0.0190	0.0057	0.0057	0.0010	4.9561
			SUBTOTAL EMISSIONS - MATERIAL PLACEMENT	**5.6303**	**5.8459**	**16.8622**	**22.4036**	**1.0859**	**1.0806**	**0.0766**	**3493**
***LONG-TERM MONITORING* (12 hours/day)**											
	Work Boat 1	Two-stroke Outboard (WB)	Assume each work day contains one 12 hr-shift. Assume a total of 8 monitoring events based on: a pre-construction baseline sampling, a construction monitoring/confirmational sampling, and long-term monitoring at years 1, 3, 5, 10, 15, and 20.	0.2986	0.3087	0.6932	0.0205	0.0062	0.0062	0.0011	5.3318
			SUBTOTAL EMISSIONS - LONG-TERM MONITORING	**0.2986**	**0.3087**	**0.6932**	**0.0205**	**0.0062**	**0.0062**	**0.0011**	**5.3**
			TOTAL EMISSIONS (metric tons, rounded)	**39**	**40**	**120**	**190**	**8.3**	**8.2**	**0.39**	**22,000**

General Notes:

1. Total emissions for construction equipment/vehicle are calculated as total daily diesel usage (gal/day) / production rate (units/day) x units x emission factor (g/gal) x (1E-6 metric ton/g).
2. Total emissions for rail transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   2a. Total diesel usage for train (gal) is calculated as total tonnage-distance covered (ton-mi) / train fuel economy (ton-mi/gal).
   2b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
3. Total emissions for truck transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   3a. Total diesel usage for trucks (gal) is calculated as total tonnage-distance covered (ton-mi) / truck fuel economy (ton-mi/gal).
   3b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
4. Total emissions for barge transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   4a. Total diesel usage for boats (gal) is calculated as total tonnage-distance covered (ton-mi) / barge fuel economy (ton-mi/gal).
   4b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.

AC = activated carbon; CO = carbon monoxide; CO_2 = carbon dioxide; cy = cubic yard; ENR = enhanced natural recovery; GAC = granular activated carbon; gal = gallon; HP = horse power; na = not applicable; NO_X = nitrogen oxides (NO and NO_2); PB = push boat; $PM_{2.5}$ = particulate matter less that 2.5 microns in diameter; PM_{10} = particulate matter less than 10 microns in diameter; RMC = residuals management cover; SCC = Standard Classification Code; SO_2 = sulfur dioxide; VOC = volatile organic compounds; WB = work boat

Table 10. Detailed Summary of Indirect Emissions By Activity and Alternative

Activity	Type of Equipment	Notes	Electricity Consumption Rate (kW)	Production Rate (quantity/day)	Quantity Units	Alternative 1C+(12) - Total Emissions (metric tons) Carbon Dioxide (CO_2)	Alternative 1C+(12) Nitrogen Oxides (NOx)	Alternative 1C+(12) Sulfur Dioxide (SO_2)	Alternative 2C+(12) - Total Emissions (metric tons) Carbon Dioxide (CO_2)	Alternative 2C+(12) Nitrogen Oxides (NOx)	Alternative 2C+(12) Sulfur Dioxide (SO_2)	Alternative 3C+(12) - Total Emissions (metric tons) Carbon Dioxide (CO_2)	Alternative 3C+(12) Nitrogen Oxides (NOx)	Alternative 3C+(12) Sulfur Dioxide (SO_2)	Alternative 2C+(7.5) - Total Emissions (metric tons) Carbon Dioxide (CO_2)	Alternative 2C+(7.5) Nitrogen Oxides (NOx)	Alternative 2C+(7.5) Sulfur Dioxide (SO_2)	Alternative 3E(7.5) - Total Emissions (metric tons) Carbon Dioxide (CO_2)	Alternative 3E(7.5) Nitrogen Oxides (NOx)	Alternative 3E(7.5) Sulfur Dioxide (SO_2)
SEDIMENT REMOVAL																				
Sediment Pumping (For Underpier Hydraulic Dredging) (8 hours/day)																				
	Water Treatment System	Assumed one 8-hour shift. Assumed electricity usage for water treatment of hydraulically dredged sediments.	250	40	cy sediment	110	0.12	0.12	110	0.12	0.12	110	0.12	0.12	110	0.12	0.12	700	0.76	0.80

Notes:

1. Total emissions due to operation of water treatment are calculated as total operation time (hrs) x electricity operation rate (kW) x 1 MWh/ 1000 kWh x emission factor (g/MWh) x (1E-6 metric ton/g).
2. Total operation time (hrs) is calculated as volume hydraulically dredged (cy) / production rate (cy/d) x operation time (hrs/d).

cy = cubic yard; g = gram; kW = kilowatt; MWh = megawatt hour; NO_X = nitrogen oxides (NO and NO_2); SO_2 = sulfur dioxide

Table 11a. Total Direct Emissions by Alternative

Alternative	Emissions (metric tons)							
	Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrous Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
1A(12)	19	20	64	130	5.4	5.3	0.25	16,000
1B(12)	20	21	67	140	5.6	5.5	0.26	16,000
1C+(12)	22	23	73	140	5.9	5.8	0.27	16,000
2B(12)	22	23	72	150	6.1	6.0	0.27	17,000
2C+(12)	24	25	78	150	6.3	6.2	0.29	18,000
3B(12)	23	24	77	160	6.4	6.3	0.29	18,000
3C+(12)	25	26	83	160	6.6	6.5	0.30	18,000
2C+(7.5)	26	27	85	170	7.0	6.8	0.31	19,000
3E(7.5)	39	40	120	190	8.3	8.2	0.39	22,000

Note:

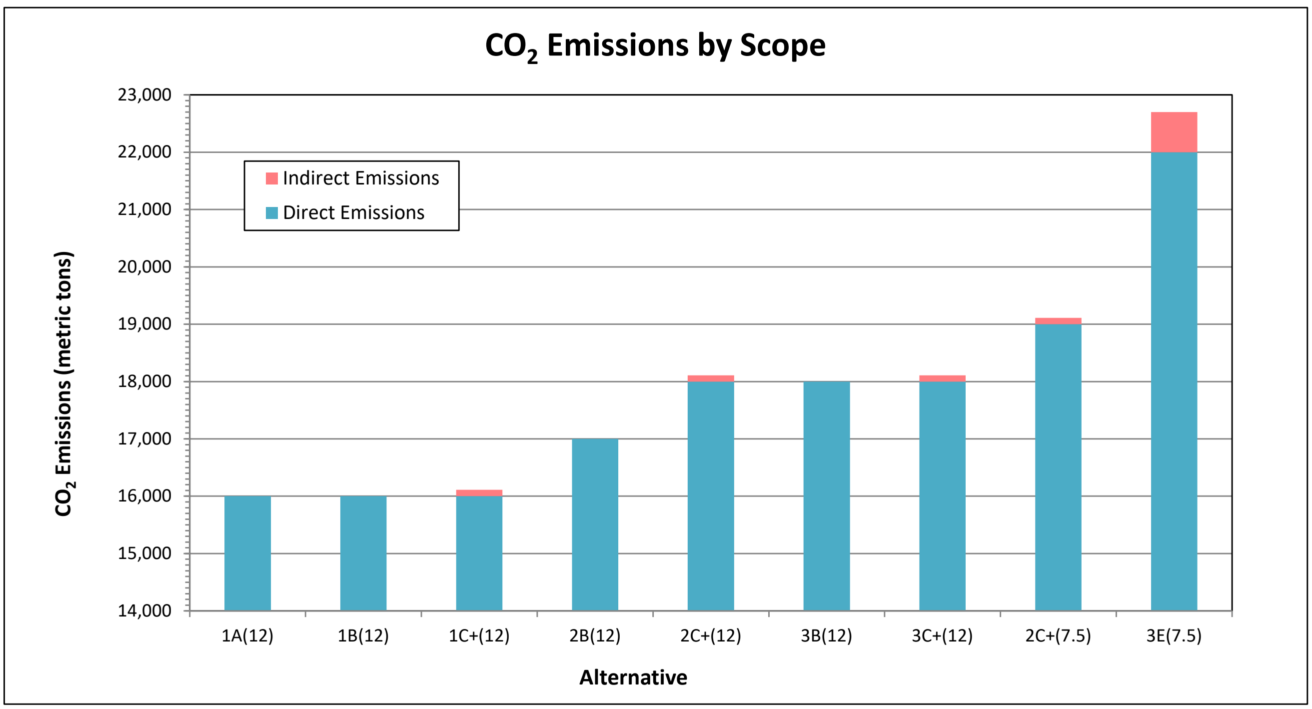
1. Total direct emissions are rounded to two significant figures, as presented in Table 9.

Table 11b. Total Indirect Emissions by Alternative

Alternative	Emissions (metric tons)		
	Carbon Dioxide (CO_2)	Nitrogen Oxides (NO_X)	Sulfur Dioxide (SO_2)
1C+(12)	110	0.12	0.12
2C+(12)	110	0.12	0.12
3C+(12)	110	0.12	0.12
2C+(7.5)	110	0.12	0.12
3E(7.5)	700	0.76	0.80

Notes:

1. Total indirect emissions account only for emissions from the water treatment associated with hydraulic dredging (Alternatives 1C+(12), 2C+(12), 3C+(12), 2C+(7.5), and 3E(7.5)).
2. Total indirect emissions are rounded to two significant figures, as presented in Table 10.



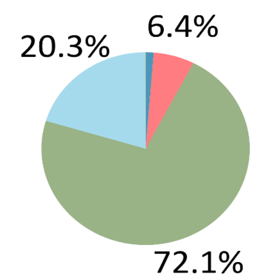
CO = carbon monoxide; CO_2 = carbon dioxide; $CO_{2\text{-eq}}$ = carbon dioxide equivalents; NO_X = nitrogen oxides (NO and NO_2); $PM_{2.5}$ = particulate matter less that 2.5 microns in diameter; PM_{10} = particulate matter less than 10 microns in diameter; SO_2 = sulfur dioxide; VOC = volatile organic compounds

Table 12. Direct CO_2 Emissions by Alternative and Contribution by Activity

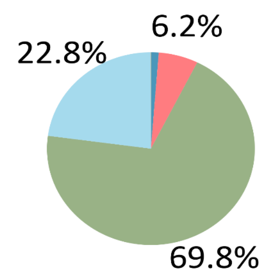
Activity	CO_2 Emissions (metric tons)									Contribution (%)								
	Alternative									Alternative								
	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Site Preparation	190	190	190	200	200	200	200	220	250	1.24%	1.21%	1.19%	1.12%	1.11%	1.12%	1.10%	1.13%	1.14%
Sediment Removal	970	970	1200	2100	1300	1200	1500	1500	3100	6.4%	6.2%	7.5%	11.8%	7.2%	6.7%	8.3%	7.7%	14.2%
Transloading and Disposal	11000	11000	11000	12000	13000	13000	13000	14000	15000	72.1%	69.8%	68.8%	67.4%	72.2%	73.0%	71.8%	72.1%	68.6%
Material Placement	3100	3600	3600	3500	3500	3400	3400	3700	3500	20.3%	22.8%	22.5%	19.7%	19.4%	19.1%	18.8%	19.0%	16.0%
Long-term Monitoring	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.02%
Total CO_2 Emissions	**16,000**	**16,000**	**16,100**	**17,000**	**18,100**	**18,000**	**18,100**	**19,100**	**22,700**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Note:
1. Direct CO_2 emissions (totals and subtotals) are rounded to two significant figures.
2. Pie chart size is proportional to total direct CO_2 emissions for each alternative.
CO_2 = carbon dioxide

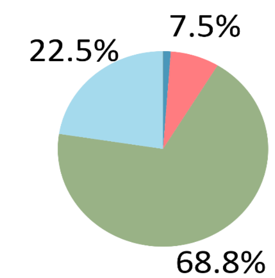
Alternative 1A(12)



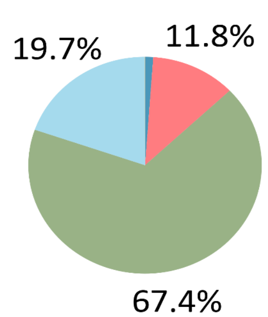
Alternative 1B(12)



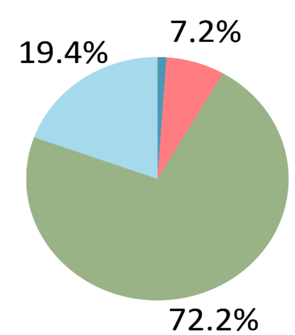
Alternative 1C+(12)



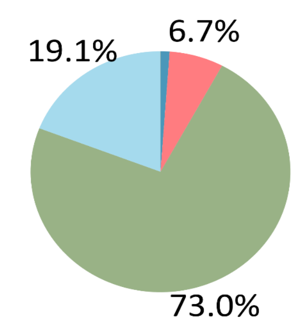
Alternative 2B(12)



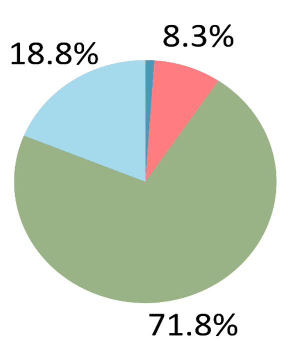
Alternative 2C+(12)



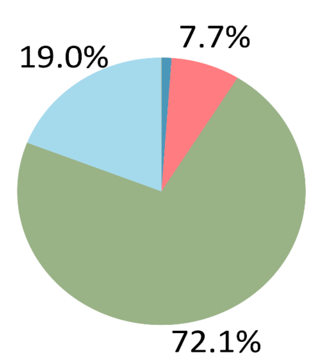
Alternative 3B(12)



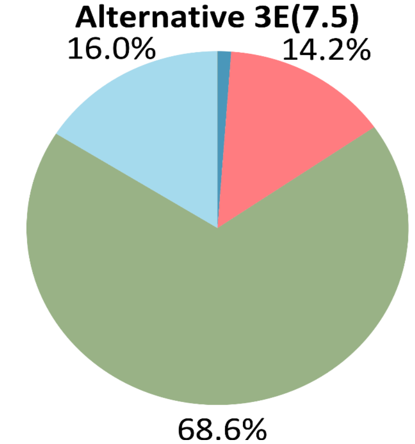
Alternative 3C+(12)



Alternative 2C+(7.5)



Alternative 3E(7.5)



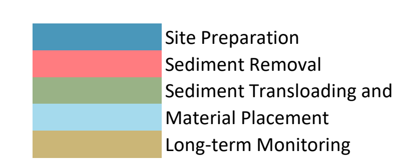


Table 13. Equivalencies of Total CO_2 Emissions

Alternative	Estimated Total CO_2 Emissions (metric tons)[b]	Equivalents to Alternative Emissions[a]		
		Number of Passenger Vehicles with Annual CO_2-eq Emissions[c]	Number of Barrels of Oil Consumed Resulting in CO_2 Emissions[d]	Number of Homes with CO_2 Emissions Due to Annual Energy Usage[e]
1A(12)	16,000	3,300	37,000	1,700
1B(12)	16,000	3,300	37,000	1,700
1C+(12)	16,100	3,400	37,000	1,700
2B(12)	17,000	3,500	40,000	1,800
2C+(12)	18,100	3,800	42,000	1,900
3B(12)	18,000	3,800	42,000	1,900
3C+(12)	18,100	3,800	42,000	1,900
2C+(7.5)	19,100	4,000	44,000	2,000
3E(7.5)	22,700	4,700	53,000	2,400

Notes:

a. Values presented were generated from EPA's Greenhouse Gas Equivalencies Calculator (http://www.epa.gov/cleanrgy/energy-resources/calculator.html), and have been rounded herein. More detailed information regarding how each calculation is derived are available at http://www.epa.gov/cleanrgy/energy-resources/refs.html.

b. Total direct and indirect CO_2 emissions by alternative available in Tables 11a and 11b.

c. Emission rate utilized is 4.8 metric tons CO_2/vehicle/year.

d. Emission rate utilized is 0.43 metric tons CO_2/barrel oil.

e. Emission rate utilized is 9.47 metric tons CO_2/home/year.

CO_2 = carbon dioxide

PART 2: OTHER SHORT-TERM EFFECTIVENESS METRICS

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1 INTRODUCTION

Six key short-term effectiveness metrics are presented in this appendix as some of the measures of this criterion used for the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) evaluation of alternatives for Sections 9 and 10 of the East Waterway (EW) Feasibility Study (FS). The primary goal of the metrics presented in this appendix is to evaluate and compare the potential impacts of the alternatives to human health and the environment during the construction phase of the remedial action; these impacts include effects on workers and the community and environmental impacts that result from construction and implementation. Other short-term effectiveness metrics, such as the length of time until RAOs are achieved, are described in detail in Section 9. A secondary objective is to identify potential best practices to help mitigate these impacts. This analysis derived metrics associated with the following factors:

- Transportation impacts associated with material hauling
- Workplace accidents during remedial activities, as expected number of injuries and fatalities
- Energy consumption
- Depleted natural resources
- Consumed landfill capacity
- Carbon footprint

Air pollutant emissions are also a key metric for evaluating the short-term effectiveness of the alternatives. An emissions inventory is presented and discussed separately in Part 1 of this appendix. An evaluation of these metrics for each alternative is also presented in Section 9.1.2.3 (Short-term Effectiveness) of the FS.

The U.S. Environmental Protection Agency (EPA) *Region 10 Superfund, RCRA, LUST, and Brownfields Clean and Green Policy* (Clean and Green Policy; EPA 2010a) states that the environmental benefits of federal cleanup programs may be enhanced by promoting technologies and practices that are sustainable. Specific objectives of the Clean and Green Policy are to: 1) protect human health and the environment by achieving remedial action goals; 2) support sustainable human and ecological use and reuse of remediated land; 3) minimize impacts to water quality and water resources; 4) reduce air pollutant emissions and greenhouse gas (GHG) production; 5) minimize material use and waste production; and 6) conserve natural resources and energy. While the selection of a preferred alternative is based on the overall evaluation of nine criteria to address the CERCLA statutory requirements (short-term effectiveness being one of them), EPA's green remediation policies and guidelines will only be consulted for the selected alternative in the development of specific mitigation measures and in the adoption of sustainable practices during the remedial design phase. Best management practices (BMPs) are available for this purpose.

2 METHODOLOGY

2.1 Remedial Activities Evaluated

The following remedial activities associated with the alternatives under consideration for the EW were identified as contributing to the six key short-term effectiveness metrics and were accounted for in this analysis:

- Sediment Removal
  - Open-water dredging (mechanical)
  - Restricted access dredging (under the West Seattle Bridge)
  - Diver-assisted hydraulic dredging (in underpier areas)
  - Water treatment (due to hydraulic dredging in underpier areas)
- Sediment Transloading and Disposal
  - Mechanical offloading, which includes the following:
    - Transportation (via tug and barge) of dredged sediments to an offloading area outside the EW
    - Transportation (via rail) of dredged sediments for landfill disposal in eastern Washington state
- Capping/treatment Material Placement:
  - Transportation of materials to the EW, which includes the following:
    - Transportation (via truck) of capping materials (i.e., sand, gravel, or armor stone) from a quarry to an onshore staging area
    - Transportation (via tug and barge) of capping materials from a staging area to the EW
    - Transportation (via rail) of in situ treatment material (activated carbon) from a vendor to the EW
  - Placement of sand for residuals management cover (RMC), capping, backfill, and enhanced natural recovery (ENR)
  - Placement of gravel for capping
  - Placement of armor stone for capping
  - Placement of activated carbon for in situ treatment (in underpier areas)
  - Placement of sand for ENR (under low bridges)
- Long-term Monitoring

2.2 Assumptions of Short-term Effectiveness Metrics

Local transportation impacts (i.e., traffic, noise, and air pollution) from the implementation of the alternatives can cause important temporary adverse effects to human health and the environment within the EW and its surrounding community. These transportation impacts are quantified in this appendix as a proportion to the number of truck, train, and barge miles estimated for support of material hauling operations, both for the disposal of contaminated sediment and for the transportation of ENR (sand), capping (sand, gravel, and armor stone), and in situ treatment materials (activated carbon) to the EW. Sediment is assumed to be barged to an offloading area (assumed to be 5 miles from the EW) and disposed of by train at a landfill in eastern Washington (assumed to be in Roosevelt, Washington, 284 miles away). Capping material is assumed to be transported by truck from a local quarry to an onshore staging area (assumed to be 20 miles away) and then barged to the EW (20 miles). In situ treatment material is assumed to be transported by rail from an activated carbon vendor located in Toledo, Ohio (2,452 miles away).

Workplace accidents represent the expected number of work-related injuries and fatalities during the remedial activities. This information is calculated using the duration of the remedial activities (based on volume estimates [see FS Appendix F], estimated production rates [see FS Appendix E]), and the rates of accident (injury/fatality) per worker per year from the U.S. Department of Labor (DOL; 2014a, 2014b) for workplace activities similar to those planned for the remediation of the EW. The remedial activities considered for workplace accident estimates were dredging, sediment disposal, and transportation of capping and treatment material by truck, barge, and train. In particular, hydraulic dredging (assumed to occur in underpier areas of the EW for certain alternatives) represents a difficult and a potentially dangerous activity to implement from a worker health and safety perspective because it is a diver-assisted procedure. The risks for injury and fatality during construction increase with every hour of diver assistance for hydraulic dredging activities. A specific fatality rate per diver per year was used for this purpose based on commercial diving safety information, available from the Occupational Safety and Health Administration (OSHA).

Energy consumption refers to thermal and electrical energy used during the implementation of alternatives. All of the construction equipment and vehicles participating in the remedial activities are assumed to be operated using diesel fuels; therefore, thermal energy consumption arises from its combustion (based on the average heating value for diesel fuel of 158 megajoules per gallon [MJ/gal]). Thermal energy consumption is directly related to the total amount of diesel fuel consumed during the activity and the specific fuel consumption rate of the equipment or vehicle. Electrical energy consumption is related to the electricity purchased from the grid and is estimated as the product of equipment power demand and utilization time. The water treatment system associated with hydraulic dredging is the only equipment assumed to be operated with electricity.

Depleted natural resources refer to the consumption of materials such as sand, gravel, and armor stone for in-water placement (e.g., capping, backfilling, RMC, or ENR).

Landfill capacity consumed represents the utilization of landfill space, which is directly proportional (1.2 times, assuming a 20% bulking factor) to the volume of dredged material removed and disposed of in the landfill.

Carbon footprint is defined as the forested area necessary to absorb the carbon dioxide (CO_2) produced during the remedial activities, based on the sequestration rate for Douglas fir. Carbon is stored by plants as they photosynthesize atmospheric CO_2 into plant biomass. Subsequently, some of this plant biomass is indirectly stored as soil organic carbon during decomposition processes. The sequestration rate is a function of the form of biomass, and is usually estimated as 2.02 grams (g) CO_2/g biomass, assuming 55% carbon in the total biomass of Douglas fir (Zhou and Hemstrom 2009) and the annual vegetation growth rate for Douglas fir, whose sequestration rate is 2.06 tons of CO_2 sequestered per acre per year (EPA 2010b).

2.3 Input Data

General and site-specific data were compiled to perform the short-term effectiveness analyses. While general data comprise generic factors and constants found in databases and literature, the site-specific data relate to the manner in which the alternatives are assumed to be implemented (e.g., type and capacity of equipment and vehicles, labor requirements, production rates, fuel consumption rates, and transportation distances).

The alternative cost estimates developed in Appendix E of the FS were used as the primary basis for calculating short-term effectiveness metrics for each alternative; dredged sediment and material placement volumes and production rates for each activity were derived from that appendix.

General data used for the calculations were obtained mostly from EPA (2010b), DOL (2014a, 2014b), OSHA (2012), and Zhou and Hemstrom (2009). General and site-specific input data, classified by the remedial activities, are reported in Tables 1 through 6.

3 RESULTS AND DISCUSSION

3.1 Output Data

Output of the six key short-term effectiveness metrics are summarized in Tables 1 through 6, and Figures 1 through 6 present graphical results the for the alternatives.

Transportation impacts in terms of truck, barge, and train miles are reported in Table 1 and Figure 1. The biggest impact due to material hauling is by truck transport operations. Alternatives 1B(12) and 1C+(12) have the largest number of truck transportation miles (approximately 126,200 truck miles), closely followed by Alternatives 1A(12) and 2C+(7.5), based on similar capping material volumes that are assumed to be hauled between a local quarry to an onshore staging area. Alternatives 2C+(7.5) and 3E(7.5) result in the largest number of train transportation miles, with approximate averages of 94,000 and 100,000 miles, respectively (Table 1), closely followed by Alternatives 2B(12), 2C+(12), 3B(12), and 3C+(12), due to the disposal of large amounts of contaminated sediment at the regional landfill. Impacts from barge transportation of materials (from EW to the offloading area for the dredged sediment, and from the onshore staging area to the EW for capping materials) range between 12,500 and 13,800 miles across the alternatives.

Short-term effectiveness analyses associated with the alternatives should consider safety risks and concerns. Although managed via OSHA and other agencies, workplace accidents are a realistic outcome of remediation, and the number of injuries and fatalities are assumed to be proportional to the duration of the remedial activities. The number of injuries among alternatives is estimated to range between 2.5 and 4, primarily associated with dredging, sediment disposal, and transportation of capping and treatment material by truck, barge, and train (Table 2). For underpier areas, the EW FS assumes use of diver-assisted hydraulic dredging for Alternatives 1C+(12), 2C+(12), 3C+(12), 2C+(7.5), and 3E(7.5), which has the same safety considerations as standard hydraulic dredging, but with significant additional technical issues and safety concerns associated with divers performing underwater dredging (especially high risk for death during construction). Based on SRI chemical data (FS Section 2), volume estimates (Appendix F), and estimated production rates (Appendix E), diver-assisted hydraulic dredging is estimated to occur for 2 years under Alternatives 1C+(12), 2C+(12), 3C+(12), and 2C+(7.5), and 12 years under

Alternative 3E(7.5). Approximately 0.017 diver fatalities have been estimated for the sediment removal activities in Alternative 3E(7.5) (the highest fatality number among alternatives, Figure 2), which represents 88% of the fatalities associated with all dredging work and 58% of the total number of fatalities during overall construction of this alternative, due to the large volume of sediment targeted for hydraulic dredging (approximately 46,200 cubic yards [cy]).

Energy required during the implementation of the alternatives is based on diesel fuel combustion and includes not only the energy consumed to remove sediment and disposed of at a landfill, but also to transport and place all capping and in situ treatment materials at the EW (Table 3). The first two remedial activities equally contribute to a combined approximate of 66% of the total energy consumption, while the latter two activities account for an additional 33% (long-term monitoring is only 1% of the total consumed energy). Figure 3 shows that the increasing total energy consumption across the alternatives, ranging from approximately 1.1×10^8 MJ (for Alternative 1A(12), due to including capping, ENR, and monitored natural recovery) to approximately 1.4×10^8 MJ (for Alternative 3E(7.5), because of its large removal volume). Alternatives 1C+(12), 2C+(12), 3C+(12), 2C+(7.5), and 3E(7.5) include removal in underpier areas, which will be conducted with diver-assisted hydraulic dredging. A water treatment system, associated with hydraulically-dredged sediments, is assumed to treat dewatered liquid and contaminants from the dredged material, and will be operated with electricity. Electrical energy consumption associated with hydraulic dredging is not expected to significantly contribute to the overall energy consumption of Alternatives 1C+(12), 2C+(12), 3C+(12), and 2C+(7.5) (approximately 0.1%), but is higher for Alternative 3E(7.5) (approximately 6%).

Materials such as sand, gravel, and armor stone are assumed to be used for capping, backfilling, RMC, and ENR. Based on preliminary cap modeling in Appendix D, a 5-foot-thick cap has been estimated for the EW FS, representing 1.5 feet of armor, 1 foot of filter material, and 2.5 feet of isolation material. Table 4 and Figure 4 show the volumes of natural resources depleted for in-water placement, which are generally in the same range across alternatives, varying between 260,183 cy (for Alternative 3C+(12)) to 287,117 cy (for Alternative 1B(12)).

The landfill capacity consumed increases in proportion to the dredge volume of the alternatives. In general, Alternative 3E(7.5) results in the largest use of landfill space, with an average volume of 1,300,000 cy, based on a total removal volume of 1,080,000 cy and a 20% bulking factor (Table 5). Alternatives 1A(12) and 1B(12) (with approximately 810,000 cy removed) and 1C+(12) (with approximately 820,000 cy removed) have the smallest removal volumes across the alternatives, and, therefore, the smallest landfill capacity consumed (approximately 970,000 and 980,000 cy, respectively; Figure 5).

The carbon footprint for each alternative in Table 6 is expressed as area-year, where 1 acre represents the amount of CO_2 sequestered by 1 acre of Douglas fir forest for 1 year. Alternative 3E(7.5) has the largest carbon footprint (approximately 5,369 acre-year) based on its CO_2 emissions (22,700 metric tons) and longest period of construction (13 years). Figure 6 depicts Alternatives 1A(12) and 1B(12) with the smallest carbon footprint (3,784 acres-year each alternative) because of only 16,000 metric tons of CO_2 emissions and their 9-year construction timeframes.

3.2 Best Management Practices

The EPA *Principles for Greener Cleanups* (2009) outlines the agency's policy for evaluating and minimizing the environmental footprint of activities undertaken when cleaning up a contaminated site. Use of the BMPs recommended in EPA's green remediation guidance can help to apply the principles on a routine basis, while maintaining the cleanup objectives, ensuring protectiveness of a remedy in the EW OU, and improving its environmental outcome.

EPA's publication *Clean Fuel & Emission Technologies for Site Cleanup* (EPA 2010c) identifies a number of BMPs for reducing air pollutant emissions. These BMPs generally fall into four categories, as follows:

- Effective operation and maintenance to ensure efficiency of vehicles and field equipment
- Advanced diesel technologies
- Alternative fuels and fuel additives
- Fuel-efficient or alternative fuel vehicles

All of these BMPs are potentially applicable for the alternatives in the EW to reduce CO_2, particulate, and other air pollutant emissions (Part 1 of this appendix). Using biodiesel is one example of an alternate fuel for reducing emissions in smaller construction equipment (e.g., front-end loaders); however, higher grades of biodiesel are impractical for use in large-scale equipment because it removes deposits within the fuel tank and fuel lines, clogs existing filters, and thereby creates waste and safety issues (NBB 2010). Also, electric dredges could reduce emissions associated with dredging activities; however, this technology is relatively new and not widely used; it might not be applicable to the EW because of navigation restrictions (e.g., shore power). Examples of advanced diesel technologies include retrofitting diesel engines with diesel particulate filters. Fuel-efficient or alternative fuel vehicles, such as small trucks or hybrid cars, may be considered for site management and monitoring activities.

Additional BMPs that can be specified during remedial design to further minimize the environmental footprint of the preferred alternative include the following (EPA 2008a, 2008b, 2010a, 2010c):

- Recycle uncontaminated materials removed from the EW (i.e., metals, construction debris, tires, etc.).
- Limit on-site vehicle speed on land to reduce particle suspension and increase fuel efficiency.
- Select fuel-efficient equipment and vehicles and alternative fuel vehicles (e.g., electric, hybrid, or compressed natural gas).
- Select suitable types of equipment and vehicles capable of handling alternative fuels (e.g., ultra-low sulfur diesel or biomass-based renewable fuel) and fuel additives (e.g., emulsified diesel or cetane enhancers) to improve fuel economy and lower GHG emissions.
- Select equipment fitted with advanced emission control systems (e.g., diesel oxidation catalyst, diesel particulate matter filter, partial diesel particulate filter, diesel multi-stage filter, or selective catalytic reduction).
- Select lower GHG-emitting fuel sources (e.g., biodiesel) for small equipment and trucks.
- Impose idling restrictions on construction equipment to increase fuel efficiency and reduce GHG emissions.
- Provide alternatives to diesel-powered generators for use during construction.

- Analyze various alternative technologies that could reduce energy consumption, waste, and emissions.
- Select fuel efficient modes of transportation for movement of materials (e.g., rail and barge versus truck transport).
- Select equipment and processes that minimize water use, and promote reuse and water conservation.
- Select reused, reusable, recycled, and recyclable materials to the greatest extent practical.
- Conduct and document routine equipment and vehicle maintenance.
- Accurately delineate contaminated sediment and sediment management areas to minimize dredging volume.
- Perform construction sequentially in a manner intended to reduce unnecessary movement of construction equipment.
- Select a landfill that collects methane.
- Incorporate sustainable site design.

A number of the operation and maintenance BMPs may be applicable to all of the alternatives during construction. These include the following:

- Reduce vehicle idling.
- Maintain equipment.
- Follow transportation and site management plans that emphasize fuel efficiency and proper fuel handling.
- Obtain materials and equipment locally to minimize shipping and mobilization distance.
- Encourage construction personnel to carpool to and from the site.

Another aspect of construction is ensuring the safety of all personnel. To prevent accidents, safety BMPs such as the following could be used:

- Complete a safety plan and ensure that all personnel are familiar with it.
- Provide proper safety equipment.
- Perform daily safety tailgate meetings to discuss potential hazards.
- Perform regular safety audits.
- Maintain a site safety officer on site at all times.

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TABLES

Table 1. Transportation Impacts

Activity/Parameter	Units	Alternative [a] 1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
SEDIMENT DISPOSAL [b]										
Total Dredge Volume [c]	cy	853,776	853,776	861,142	947,323	954,689	1,002,861	1,010,227	1,065,653	1,136,135
Distance from EW to Offloading Area	miles	5	5	5	5	5	5	5	5	5
Distance from Offloading Area to Landfill	miles	284	284	284	284	284	284	284	284	284
Barge Capacity	cy	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
Railcar Capacity [d]	cy	67	67	67	67	67	67	67	67	67
SUBTOTAL TRANSPORTATION - SEDIMENT DISPOSAL (miles)	***Barge***	**5,300**	**5,300**	**5,400**	**5,900**	**6,000**	**6,300**	**6,300**	**6,700**	**7,100**
	Rail	**72,400**	**72,400**	**73,000**	**80,300**	**80,900**	**85,000**	**85,600**	**90,300**	**96,300**
CAPPING/TREATMENT MATERIAL TRANSPORTATION [e]										
Capping Material Volume	cy	285,701	286,307	286,241	275,155	275,092	259,084	258,761	284,204	267,363
Sand Material Volume (Low Bridges)	cy	811	811	811	1,421	1,421	1,421	1,421	1,562	1,562
In situ Treatment Material (Activated Carbon) Volume (Underpiers)	cy	0	4,867	4,867	4,867	4,867	4,867	4,867	5,113	5,113
Distance from Quarry to Shore (for Capping Material)	miles	20	20	20	20	20	20	20	20	20
Distance from Shore to EW (for Capping Material)	miles	20	20	20	20	20	20	20	20	20
Distance from Vendor in OH to EW (for Activated Carbon)	miles	2,452	2,452	2,452	2,452	2,452	2,452	2,452	2,452	2,452
Truck Capacity	cy	13	13	13	13	13	13	13	13	13
Barge Capacity	cy	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
Railcar Capacity [d]	cy	67	67	67	67	67	67	67	67	67
SUBTOTAL TRANSPORTATION - CAPPING/TREATMENT MATERIAL TRANSPORTATION (miles)	***Truck***	**125,900**	**126,200**	**126,200**	**121,600**	**121,500**	**114,500**	**114,400**	**125,600**	**118,200**
	Barge	**7,200**	**7,200**	**7,200**	**6,900**	**6,900**	**6,500**	**6,500**	**7,100**	**6,700**
	Rail	**0**	**3,600**	**3,600**	**3,600**	**3,600**	**3,600**	**3,600**	**3,700**	**3,700**

TOTAL TRANSPORTATION IMPACTS (miles)	***Truck***	**125,900**	**126,200**	**126,200**	**121,600**	**121,500**	**114,500**	**114,400**	**125,600**	**118,200**
	Barge	**12,500**	**12,500**	**12,600**	**12,800**	**12,900**	**12,800**	**12,800**	**13,800**	**13,800**
	Rail	**72,400**	**76,000**	**76,600**	**83,900**	**84,500**	**88,600**	**89,200**	**94,000**	**100,000**

Notes:

a. Quantities and production rates by alternative were obtained from Appendix E.

b. Dredged sediments are assumed to be hauled to an offloading area outside of the EW (by barge) and disposed of at a Subtitle D landfill in Roosevelt, Washington (by rail).

c. Assumes bulking factor of 5% for mechanical offloading.

d. Rail transportation assumes that all trains will consist of a full unit train of 100 railcars.

e. Capping materials are assumed to be transported from a local quarry to an onshore staging area by truck, and then to the EW by barge.

cy - cubic yard; EW - East Waterway

Table 2. Predicted Workplace Accidents

Activity/Parameter	Units	Alternative [g]								
		1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
SEDIMENT REMOVAL										
Open-water Dredge Volume	cy	813,120	813,120	813,120	902,212	902,212	938,455	938,455	1,007,892	1,016,453
Production Rate	cy/d	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
Restricted Access Dredge Volume (Under West Seattle Bridge)	cy	0	0	0	0	0	16,651	16,651	0	19,365
Production Rate	cy/d	270	270	270	270	270	270	270	270	270
Diver-Assisted Hydraulic Dredge Volume (Underpiers)	cy	0	0	7,016	0	7,016	0	7,016	7,016	46,216
Production Rate	cy/d	40	40	40	40	40	40	40	40	40
Working Days per Season	days	100	100	100	100	100	100	100	100	100
Number of Construction Equipment Operators - Open-water Dredging	worker	3	3	3	3	3	3	3	3	3
Number of Divers - Underpier Dredging [a]	diver	0	0	1	0	1	0	1	1	1
Number of Construction Equipment Operators - Underpier Dredging [a]	worker	0	0	5	0	5	0	5	5	5
Injury Rate for Heavy and Civil Engineering Construction [b]	injuries/worker/year	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Fatality Rate for Operating Engineers and Other Construction Equipment Operators [c]	fatalities/worker/year	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075
Fatality Rate for Commercial Diving [d]	fatalities/diver/year	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
SUBTOTAL PREDICTED ACCIDENTS - SEDIMENT REMOVAL	***Predicted Injuries***	**0.67**	**0.67**	**0.82**	**0.74**	**0.90**	**0.82**	**0.98**	**0.98**	**1.94**
	Predicted Fatalities - Open-water Dredging	**0.0017**	**0.0017**	**0.0017**	**0.0018**	**0.0018**	**0.0021**	**0.0021**	**0.0021**	**0.0022**
	Predicted Fatalities - Underpier Dredging	**0**	**0**	**0.0023**	**0**	**0.0023**	**0.0000**	**0.0026**	**0.0026**	**0.0170**
	Total Predicted Fatalities	**0.0017**	**0.0017**	**0.0040**	**0.0018**	**0.0042**	**0.0021**	**0.0046**	**0.0046**	**0.0193**
SEDIMENT TRANSLOADING AND DISPOSAL										
Total Dredge Volume [e]	cy	853,776	853,776	861,142	947,323	954,689	1,002,861	1,010,227	1,065,653	1,136,135
Offloading Rate	cy/d	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200
Distance from EW to Offloading Area	miles	5	5	5	5	5	5	5	5	5
Distance from Offloading Area to Landfill [f]	miles	284	284	284	284	284	284	284	284	284
Barge Capacity	cy	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
Tug Speed	mi/hr	5	5	5	5	5	5	5	5	5
Railcar Capacity	cy	67	67	67	67	67	67	67	67	67
Train Speed	mi/hr	50	50	50	50	50	50	50	50	50
Working Hours per Day	hours	12	12	12	12	12	12	12	12	12
Working Days per Season	days	100	100	100	100	100	100	100	100	100
Number of Construction/Water Equipment Operators	worker	3	3	3	3	3	3	3	3	3
Number of Rail Operators	worker	8	8	8	8	8	8	8	8	8
Injury Rate for Heavy and Civil Engineering Construction [b]	injuries/worker/year	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Fatality Rate for Operating Engineers and Other Construction Equipment Operators [c]	fatalities/worker/year	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075
Injury Rate for Inland Water Freight Transportation	injuries/worker/year	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Fatality Rate for Water Transportation	fatalities/worker/year	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031
Injury Rate for Rail Transportation [a]	injuries/worker/year	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Fatality Rate for Rail Transportation [c]	fatalities/worker/year	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006
SUBTOTAL PREDICTED ACCIDENTS - SEDIMENT TRANSLOADING AND DISPOSAL	***Predicted Injuries***	**0.59**	**0.59**	**0.60**	**0.66**	**0.66**	**0.70**	**0.70**	**0.74**	**0.79**
	Predicted Fatalities	**0.0023**	**0.0023**	**0.0023**	**0.0025**	**0.0025**	**0.0027**	**0.0027**	**0.0028**	**0.0030**

Table 2. Predicted Workplace Accidents

Activity/Parameter	Units	Alternative [g]								
		1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
CAPPING/TREATMENT MATERIAL TRANSPORTATION										
Capping Material Volume	cy	285,701	286,307	286,241	275,155	275,092	259,084	258,761	284,204	267,363
Sand Material Volume (Low Bridges)	cy	811	811	811	1,421	1,421	1,421	1,421	1,562	1,562
In situ Treatment Material (Activated Carbon) Volume (Underpiers)	cy	0	4,867	4,867	4,867	4,867	4,867	4,867	5,113	5,113
Distance from Quarry to Shore (for Capping Material)	miles	20	20	20	20	20	20	20	20	20
Distance from Shore to EW (for Capping Material)	miles	20	20	20	20	20	20	20	20	20
Distance from Vendor in OH to EW (for Activated Carbon)	miles	2,452	2,452	2,452	2,452	2,452	2,452	2,452	2,452	2,452
Truck Capacity	cy	13	13	13	13	13	13	13	13	13
Truck Speed	mi/hr	40	40	40	40	40	40	40	40	40
Barge Capacity	cy	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
Tug Speed	mi/hr	5	5	5	5	5	5	5	5	5
Railcar Capacity	cy	67	67	67	67	67	67	67	67	67
Train Speed	mi/hr	50	50	50	50	50	50	50	50	50
Working Hours per Day	hours	12	12	12	12	12	12	12	12	12
Working Days per Season	days	100	100	100	100	100	100	100	100	100
Number of Truck Operators	worker	7	7	7	7	7	7	7	7	7
Number of Water Equipment Operators	worker	2	2	2	2	2	2	2	2	2
Number of Train Operators	worker	8	8	8	8	8	8	8	8	8
Injury Rate for General Freight Trucking, local [b]	injuries/worker/year	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
Fatality Rate for Truck Transportation [c]	fatalities/worker/year	0.000239	0.000239	0.000239	0.000239	0.000239	0.000239	0.000239	0.000239	0.000239
Injury Rate for Inland Water Freight Transportation [b]	injuries/worker/year	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Fatality Rate for Water Transportation [c]	fatalities/worker/year	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031
Injury Rate for Rail Transportation [b]	injuries/worker/year	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Fatality Rate for Rail Transportation [c]	fatalities/worker/year	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006
SUBTOTAL PREDICTED ACCIDENTS -	***Predicted Injuries***	**0.84**	**0.86**	**0.86**	**0.82**	**0.82**	**0.78**	**0.78**	**0.85**	**0.80**
CAPPING/TREATMENT MATERIAL TRANSPORTATION	***Predicted Fatalities***	**0.0051**	**0.0052**	**0.0052**	**0.0050**	**0.0050**	**0.0047**	**0.0047**	**0.0051**	**0.0048**
CAPPING/TREATMENT MATERIAL PLACEMENT										
Sand Capping Volume	cy	234,151	234,756	234,690	223,604	223,541	229,661	229,338	232,434	237,720
Production Rate	cy/d	940	940	940	940	940	940	940	940	940
Gravel Capping Volume	cy	20,620	20,620	20,620	20,620	20,620	11,769	11,769	20,708	11,857
Production Rate	cy/d	940	940	940	940	940	940	940	940	940
Armor Stone Capping Volume	cy	30,931	30,931	30,931	30,931	30,931	17,654	17,654	31,062	17,786
Production Rate	cy/d	560	940	940	940	940	940	940	940	940
In situ Treatment Material Volume	cy	0	4,867	4,867	4,867	4,867	4,867	4,867	5,113	5,113
Production Rate	cy/d	60	60	60	60	60	61	60	60	60
Sand Material Volume (Low Bridges)	cy	811	811	811	1,421	1,421	1,421	1,421	1,562	1,562
Production Rate	cy/d	60	60	60	60	60	61	60	60	60
Working Days per Season	days	100	100	100	100	100	100	100	100	100
Number of Construction Equipment Operators	worker	3	3	3	3	3	4	3	3	3
Injury Rate for Heavy and Civil Engineering Construction [b]	injuries/worker/year	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Fatality Rate for Operating Engineers and Other Construction Equipment Operators [c]	fatalities/worker/year	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075	0.000075
SUBTOTAL PREDICTED ACCIDENTS -	***Predicted Injuries***	**0.31**	**0.36**	**0.36**	**0.36**	**0.36**	**0.45**	**0.34**	**0.37**	**0.36**
MATERIAL PLACEMENT	***Predicted Fatalities***	**0.0008**	**0.0009**	**0.0009**	**0.0009**	**0.0009**	**0.0011**	**0.0009**	**0.0009**	**0.0009**

Table 2. Predicted Workplace Accidents

Activity/Parameter	Units	Alternative [g] 1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
LONG-TERM MONITORING										
Construction Seasons	year	9	9	9	10	10	10	10	11	13
Number of Monitoring Events	event	8	8	8	8	8	8	8	8	8
Number of Water Equipment Operators	worker	3	3	3	3	3	4	3	3	3
Injury Rate for Inland Water Freight Transportation [b]	injuries/worker/year	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Fatality Rate for Water Transportation [c]	fatalities/worker/year	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031
SUBTOTAL PREDICTED ACCIDENTS -	***Predicted Injuries***	**0.0776**	**0.0776**	**0.0776**	**0.0863**	**0.0863**	**0.1150**	**0.0863**	**0.0949**	**0.1121**
LONG-TERM MONITORING	***Predicted Fatalities***	**0.0010**	**0.0010**	**0.0010**	**0.0012**	**0.0012**	**0.0016**	**0.0012**	**0.0013**	**0.0015**
TOTAL PREDICTED ACCIDENTS	***Total Predicted Injuries***	**2.49**	**2.55**	**2.71**	**2.67**	**2.83**	**2.87**	**2.89**	**3.04**	**4.00**
	Total Predicted Fatalities	**0.011**	**0.011**	**0.013**	**0.011**	**0.014**	**0.012**	**0.014**	**0.015**	**0.030**

Notes:

a. A diving crew for underpier dredging includes the diver, tender, responder/backup diver, boat operator, and two workers for the pump, dredge, lines, and other construction duties.

b. Source: U.S. Department of Labor, Bureau of Labor Statistics (Industry Injury and Illness Data for 2014, Supplemental News Release Tables [Injury cases - rates, counts, and percent relative standard errors - detailed industry - 2014 SNR05]). http://www.bls.gov/iif/oshsum.htm#14Summary_News_Release

c. Source: U.S. Department of Labor, Bureau of Labor Statistics (Census of Fatal Occupational Injuries, 2007-2012). http://www.bls.gov/iif/oshcfoi1.htm

d. An average of 6 to 13 diving fatalities occur each year, which corresponds to a risk of between 28 and 50 deaths per 1,000 workers over a working lifetime of 45 years (U.S. Department of Labor, Occupational Safety and Health Administration [Commercial Diving Safety; https://www.osha.gov/archive/oshinfo/priorities/diving.html]).

e. A bulking factor of 5% is included in the total dredge volume for mechanical offloading.

f. Sediment is assumed to be transferred from the intermodal station in Seattle, Washington, to a Subtitle D landfill in Roosevelt, Washington.

g. Quantities and production rates by alternative were obtained from Appendix E.

cy - cubic yard; d - day; EW - East Waterway

Table 3. Energy Consumption

Activity/Parameter	Units	Alternative[a] 1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
SEDIMENT REMOVAL										
Open-water Dredge Volume	cy	813,120	813,120	813,120	902,212	902,212	938,455	938,455	1,007,892	1,016,453
Production Rate	cy/d	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
Restricted Access Dredge Volume	cy	0	0	0	0	0	16,651	16,651	0	19,365
Production Rate	cy/d	270	270	270	270	270	270	270	270	270
Underpier Dredge Volume	cy	0	0	7,016	0	7,016	0	7,016	7,016	46,216
Production Rate	cy/d	40	40	40	40	40	40	40	40	40
Working Hours per Day - Open-water Dredging	hours	12	12	12	12	12	12	12	12	12
Working Hours per Day - Underpier Dredging	hours	8	8	8	8	8	8	8	8	8
Fuel Consumption - Derrick Crane	gal/hr	25	25	25	25	25	25	25	25	25
Electricity Consumption - Water Treatment	KW	250	250	250	250	250	250	250	250	250
Energy Content of Diesel Fuel	MJ/gal	158	158	158	158	158	158	158	158	158
SUBTOTAL ENERGY CONSUMPTION - SEDIMENT REMOVAL (MJ)		**3.5E+07**	**3.5E+07**	**3.6E+07**	**3.9E+07**	**4.0E+07**	**4.3E+07**	**4.5E+07**	**4.5E+07**	**5.6E+07**
SEDIMENT TRANSLOADING AND DISPOSAL										
Total Dredge Volume[b]	cy	853,776	853,776	861,142	947,323	954,689	1,002,861	1,010,227	1,065,653	1,136,135
Offloading Rate	cy/d	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200
Distance from EW to Offloading Area	miles	5	5	5	5	5	5	5	5	5
Distance from Offloading Area to Landfill[c]	miles	284	284	284	284	284	284	284	284	284
Barge Capacity	cy	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
Tug Speed	mi/hr	5	5	5	5	5	5	5	5	5
Railcar Capacity	cy	67	67	67	67	67	67	67	67	67
Working Hours per Day	hours	12	12	12	12	12	12	12	12	12
Fuel Consumption - Derrick Crane	gal/hr	25	25	25	25	25	25	25	25	25
Fuel Consumption - Tug	gal/hr	85	85	85	85	85	85	85	85	85
Fuel Consumption - Railcar	gal/mi	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Energy Content of Diesel Fuel	MJ/gal	158	158	158	158	158	158	158	158	158
SUBTOTAL ENERGY CONSUMPTION - SEDIMENT TRANSLOADING AND DISPOSAL (MJ)		**3.5E+07**	**3.5E+07**	**3.6E+07**	**3.9E+07**	**3.9E+07**	**4.1E+07**	**4.2E+07**	**4.4E+07**	**4.7E+07**

Table 3. Energy Consumption

Activity/Parameter	Units	Alternative[a] 1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
CAPPING/TREATMENT MATERIAL TRANSPORTATION										
Capping Material Volume	cy	285,701	286,307	286,241	275,155	275,092	259,084	258,761	284,204	267,363
Sand Material Volume (Low Bridges)	cy	811	811	811	1421	1421	1421	1421	1562	1562
In situ Treatment Material Volume	cy	0	4,867	4,867	4,867	4,867	4,867	4,867	5,113	5,113
Distance from Quarry to Shore (for Capping Material)	miles	20	20	20	20	20	20	20	20	20
Distance from Shore to EW (for Capping Material)	miles	20	20	20	20	20	20	20	20	20
Distance from Vendor in OH to EW (for Activated Carbon)	miles	2,452	2,452	2,452	2,452	2,452	2,452	2,452	2,452	2,452
Truck Capacity	cy	13	13	13	13	13	13	13	13	13
Truck Speed	mi/hr	40	40	40	40	40	40	40	40	40
Barge Capacity	cy	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
Tug Speed	mi/hr	5	5	5	5	5	5	5	5	5
Railcar Capacity	cy	67	67	67	67	67	67	67	67	67
Fuel Consumption - Truck	gal/mi	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Fuel Consumption - Tug	gal/hr	85	85	85	85	85	85	85	85	85
Fuel Consumption - Railcar	gal/mi	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Energy Content of Diesel Fuel	MJ/gal	158	158	158	158	158	158	158	158	158
SUBTOTAL ENERGY CONSUMPTION - CAPPING/TREATMENT MATERIAL TRANSPORTATION (MJ)		**2.3E+07**	**2.3E+07**	**2.3E+07**	**2.2E+07**	**2.2E+07**	**2.1E+07**	**2.1E+07**	**2.3E+07**	**2.2E+07**
CAPPING/TREATMENT MATERIAL PLACEMENT										
Sand Capping Volume	cy	234,151	234,756	234,690	223,604	223,541	229,661	229,338	232,434	237,720
Production Rate	cy/d	940	940	940	940	940	940	940	940	940
Gravel Capping Volume	cy	20,620	20,620	20,620	20,620	20,620	11,769	11,769	20,708	11,857
Production Rate	cy/d	940	940	940	940	940	940	940	940	940
Armor Stone Capping Volume	cy	30,931	30,931	30,931	30,931	30,931	17,654	17,654	31,062	17,786
Production Rate	cy/d	560	940	940	940	940	940	940	940	940
In situ Treatment Material Volume	cy	0	4,867	4,867	4,867	4,867	4,867	4,867	5,113	5,113
Production Rate	cy/d	60	60	60	60	60	61	60	60	60
Sand Material Volume (Low Bridges)	cy	811	811	811	1421	1421	1421	1421	1562	1562
Production Rate	cy/d	60	60	60	60	60	60	60	60	60
Working Hours per Day	hours	12	12	12	12	12	12	12	12	12
Fuel Consumption - Derrick Crane	gal/hr	25	25	25	25	25	25	25	25	25
Energy Content of Diesel Fuel	MJ/gal	158	158	158	158	158	158	158	158	158
SUBTOTAL ENERGY CONSUMPTION - MATERIAL PLACEMENT (MJ)		**1.6E+07**	**1.9E+07**	**1.9E+07**	**1.9E+07**	**1.9E+07**	**1.8E+07**	**1.8E+07**	**2.0E+07**	**1.9E+07**

Table 3. Energy Consumption

Activity/Parameter	Units	Alternative[a]								
		1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
LONG-TERM MONITORING										
Number of Monitoring Events	event	8	8	8	8	8	8	8	8	8
Working Hours per Day	hours	12	12	12	12	12	12	12	12	12
Fuel Consumption - Tug	gal/hr	85	85	85	85	85	85	85	85	85
Energy Content of Diesel Fuel	MJ/gal	158	158	158	158	158	158	158	158	158
SUBTOTAL ENERGY CONSUMPTION - LONG-TERM MONITORING (MJ)		**1.3E+06**	**1.3E+06**	**1.3E+06**	**1.3E+06**	**1.3E+06**	**1.3E+06**	**1.3E+06**	**1.3E+06**	**1.3E+06**
TOTAL ENERGY CONSUMPTION (MJ)		**1.11E+08**	**1.14E+08**	**1.15E+08**	**1.21E+08**	**1.22E+08**	**1.25E+08**	**1.27E+08**	**1.33E+08**	**1.44E+08**

Notes:

a. Quantities and production rates by alternative were obtained from Appendix E.

b. A bulking factor of 5% is included in the total dredge volume for mechanical offloading.

c. Sediment is assumed to be transferred from the intermodal station in Seattle, Washington, to a Subtitle D landfill in Roosevelt, Washington.

cy - cubic yard; d - day; EW - East Waterway; gal - gallon; hr - hour; kW - kilowatt-hour; mi - mile; MJ - megajoule

Table 4. Depleted Natural Resources

Parameter	Units	Alternative								
		1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Sand, Gravel and Armor Stone Used for Placement	cy	286,512	287,117	287,051	276,576	276,513	260,506	260,183	285,766	268,925

Table 5. Consumed Landfill Capacity

Parameter	Units	Alternative								
		1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Total Removal Volume	cy	810,000	810,000	820,000	900,000	910,000	960,000	960,000	1,010,000	1,080,000
Landfill Capacity Consumed	cy	970,000	970,000	980,000	1,080,000	1,090,000	1,150,000	1,150,000	1,210,000	1,300,000

Note:

a. The landfill capacity consumed is proportional to the volume of dredged material removed and disposed of in the landfill (assuming a 20% bulking factor).

Table 6. Carbon Footprint

Parameter	Units	Alternative								
		1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
CO_2 emissions	tonnes	16,000	16,000	16,100	17,000	18,100	18,000	18,100	19,100	22,700
CO_2 absorbed	g CO_2/g biomass	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
Sequestration rate for Douglas fir in Pacific Northwest	tons CO_2/acre-year	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06
Construction timeframe	year	9	9	9	10	10	10	10	11	13
Carbon Footprint (acres-years)		**3,784**	**3,784**	**3,808**	**4,021**	**4,281**	**4,257**	**4,281**	**4,518**	**5,369**

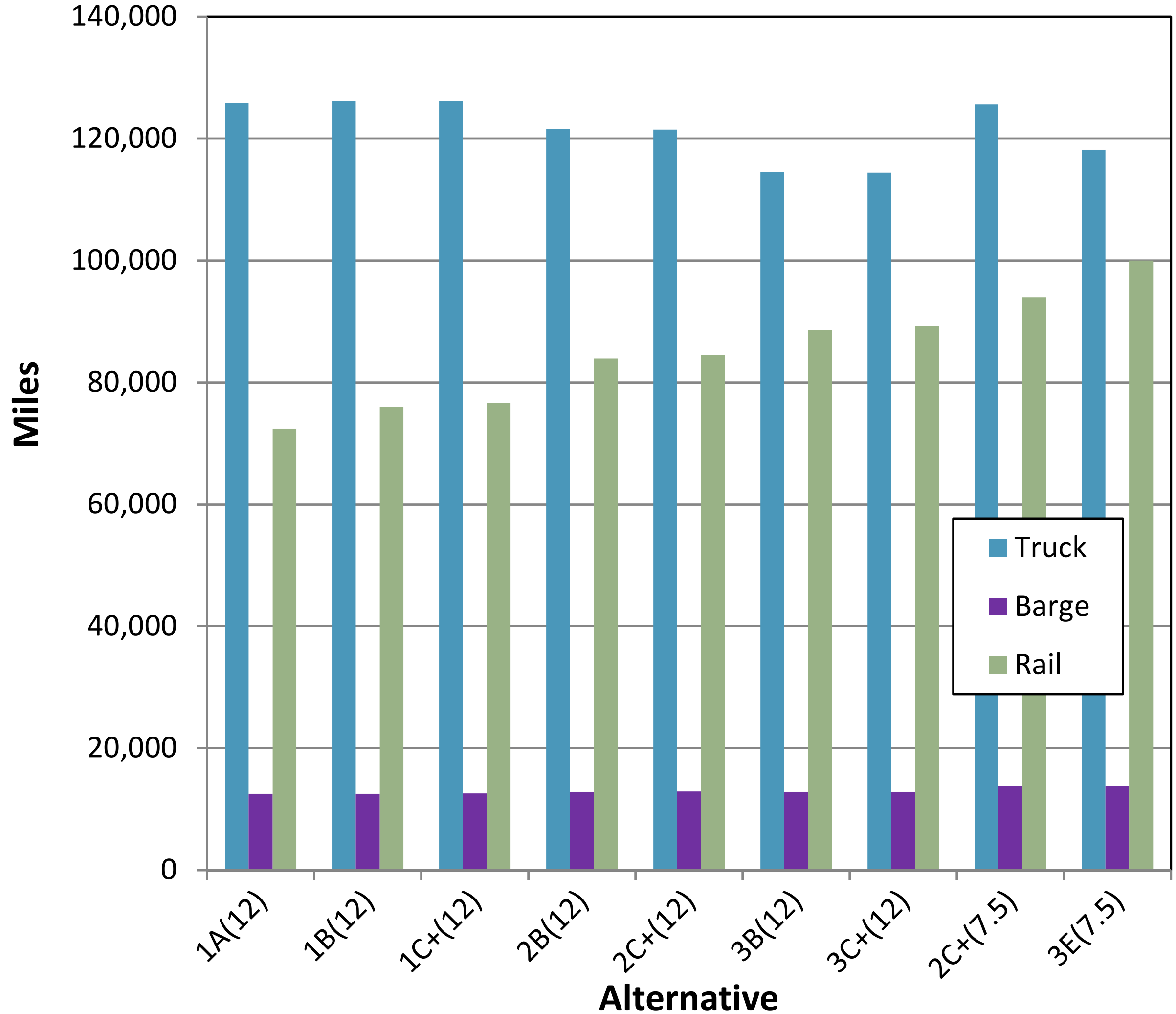
Notes:

a. Total direct and indirect CO_2 emissions by alternative available in Appendix I, Part 1, Tables 11a and 11b.

b. The Douglas fir growth rate represent the amount of CO_2 sequestered by 1 acre of Douglas fir forest for 1 year.

CO_2 - carbon dioxide; cy - cubic yard; g - gram

FIGURES



Note:
Impacts from truck transportation could be effectively reduced by increased barge transportation.

Figure 1
Transportation Impacts
Feasibility Study - Appendix I, Part 2
East Waterway Study Area

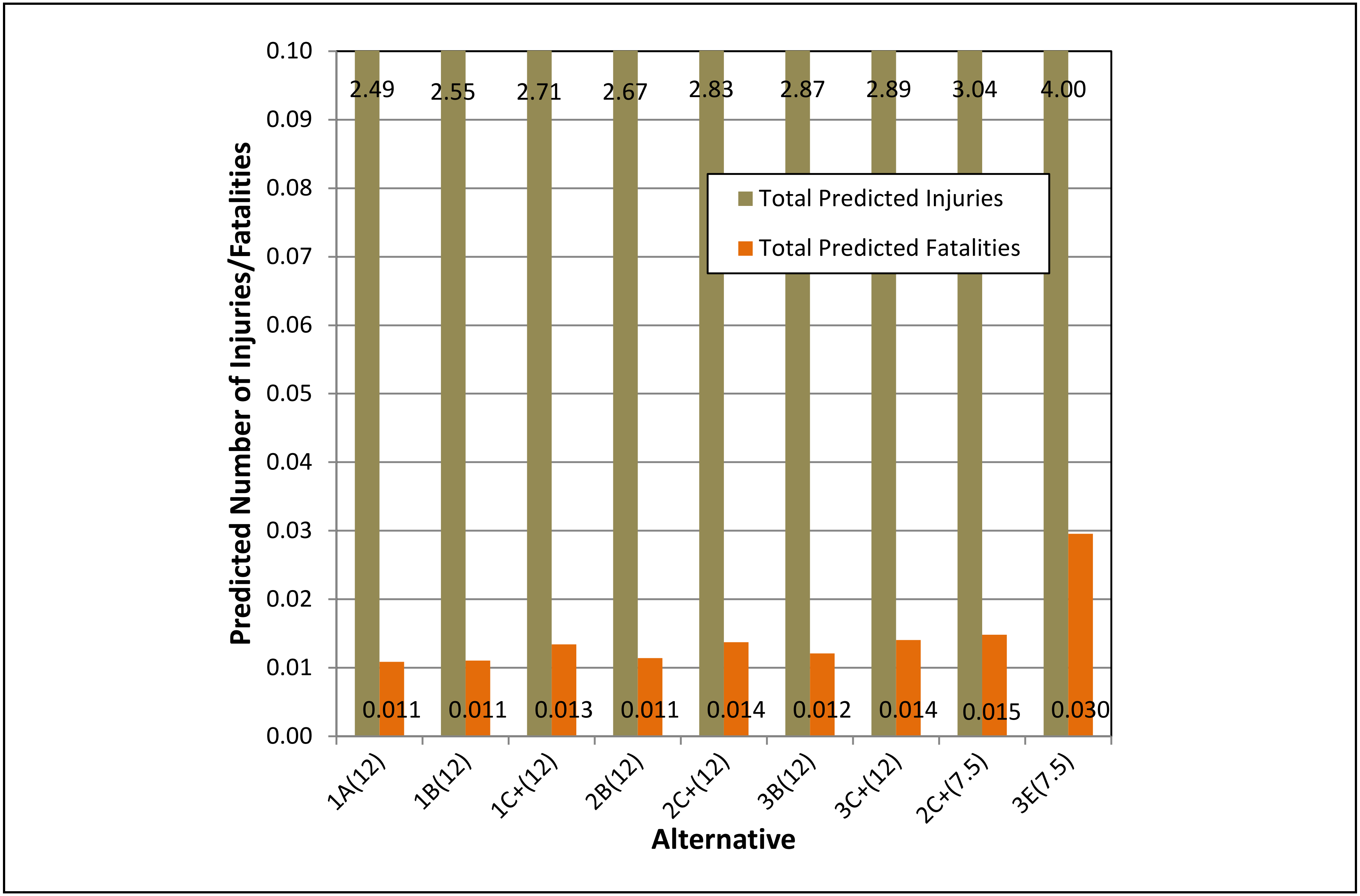


Figure 2
Predicted Workplace Accidents
Feasibility Study - Appendix I, Part 2
East Waterway Study Area

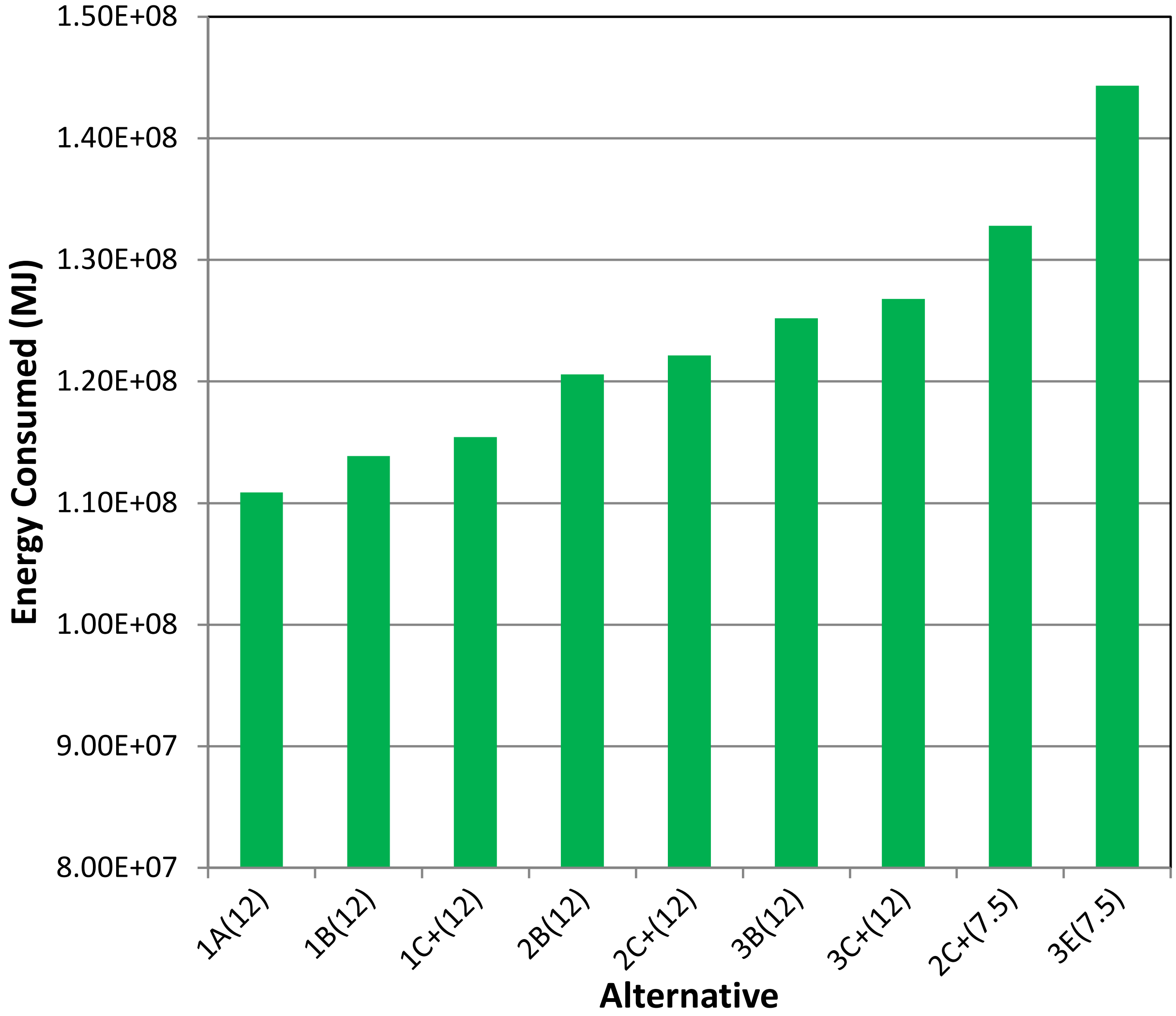


Figure 3
Energy Consumption
Feasibility Study - Appendix I, Part 2
East Waterway Study Area

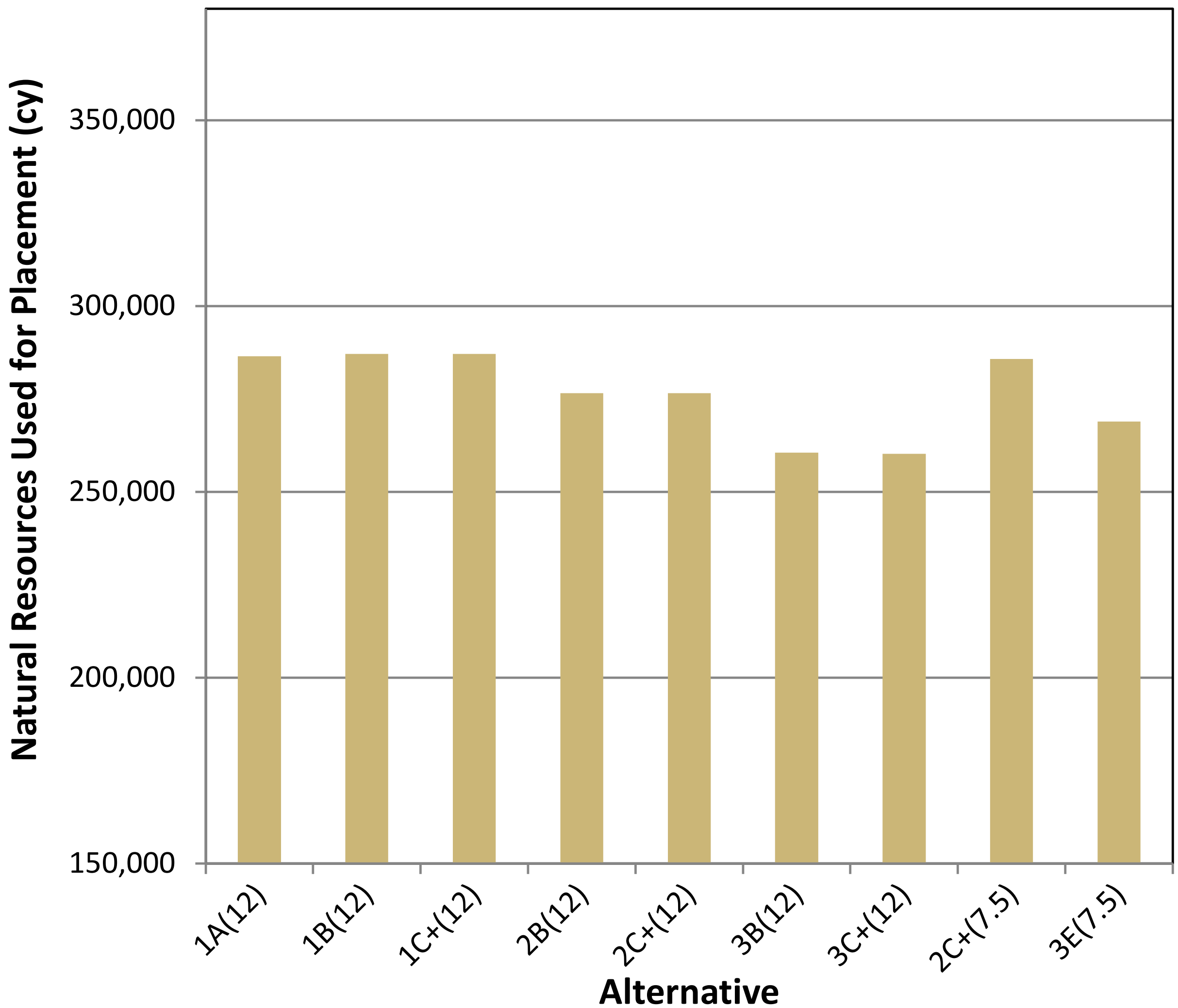


Figure 4
Depleted Natural Resources
Feasibility Study - Appendix I, Part 2
East Waterway Study Area

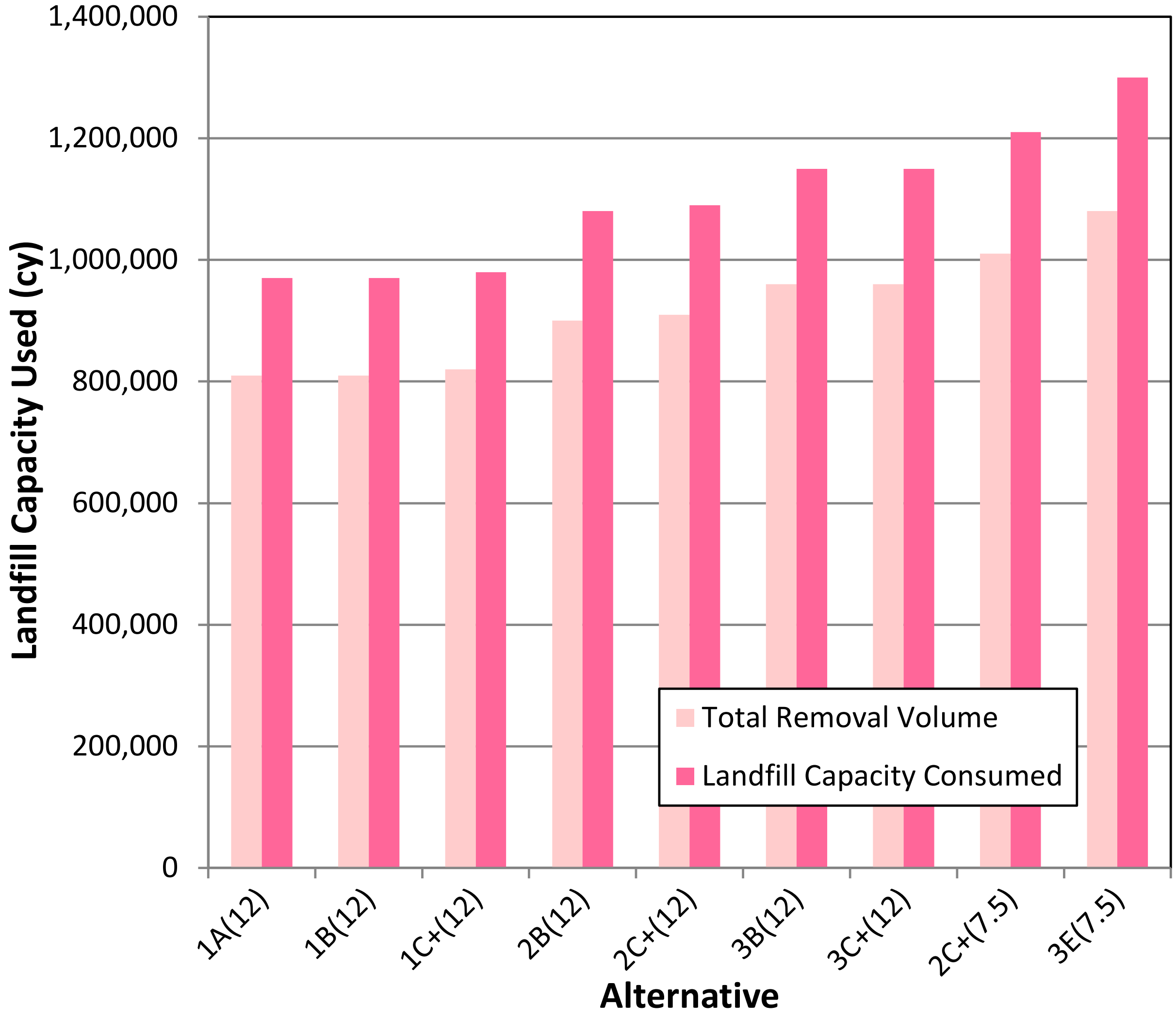


Figure 5
Consumed Landfill Capacity
Feasibility Study - Appendix I, Part 2
East Waterway Study Area

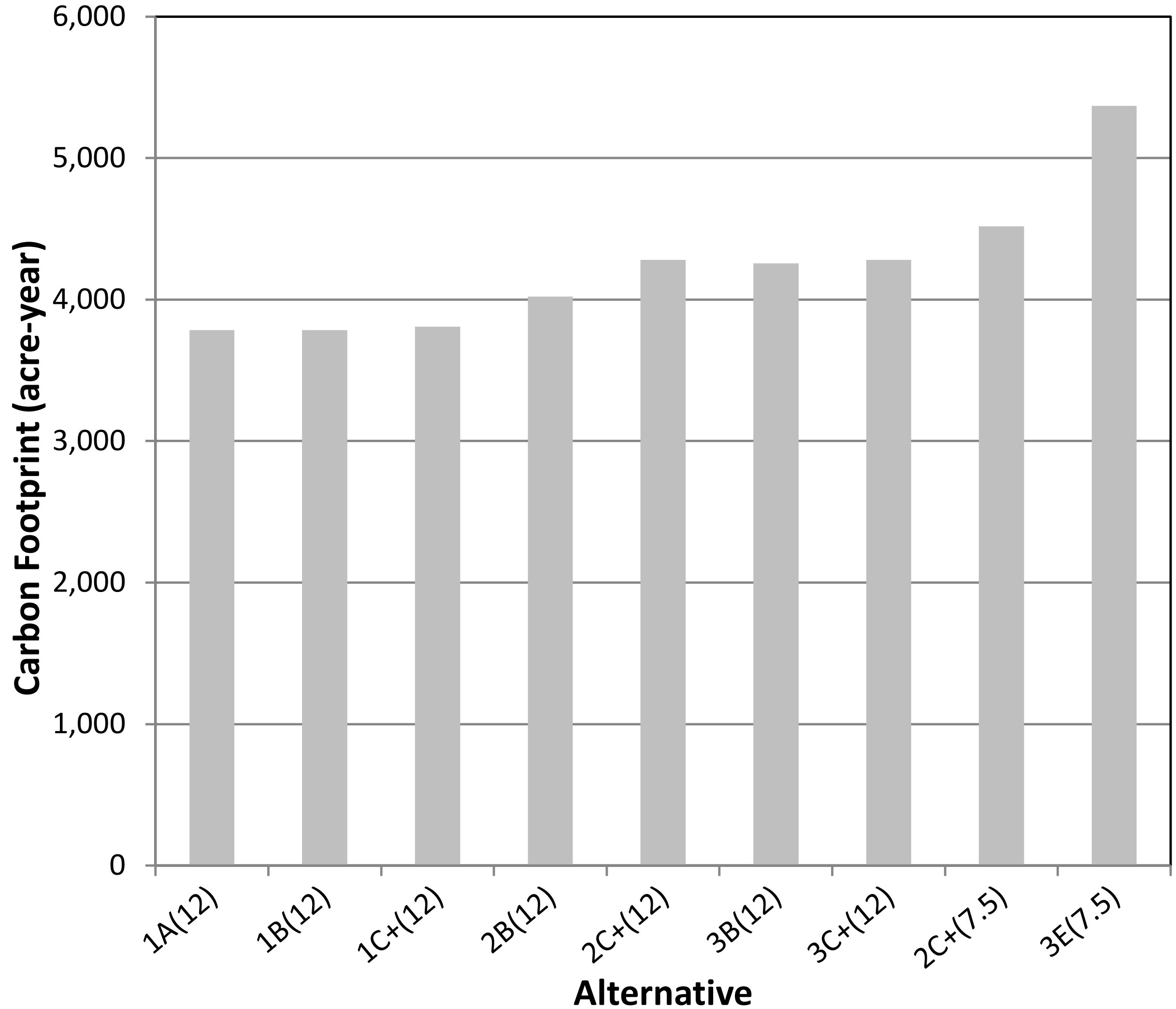


Figure 6
Carbon Footprint
Feasibility Study - Appendix I, Part 2
East Waterway Study Area

APPENDIX J – DETAILED CALCULATIONS AND SENSITIVITY ANALYSES FOR PREDICTIVE EVALUATION OF SITE PERFORMANCE OVER TIME AND RECONTAMINATION POTENTIAL

EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

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1 INTRODUCTION

This appendix provides the mathematical basis for contaminant concentration predictions for East Waterway (EW) remedial alternatives presented in the Feasibility Study (FS). The purpose of each of the predictive evaluations discussed in this appendix is described in detail in FS Section 5. Remedial technologies for use in the EW are described in FS Section 7, and descriptions of remedial alternatives are provided in FS Section 8.

This appendix provides a summary of input information, methodology, mathematical calculations, and rationale for model assumptions for each of the three predictive evaluations presented in Section 5:

- Site-wide Performance Over Time (referred to as the "box model evaluation") (Section 2 of this appendix, FS Section 5.3)
- Remedial action objective (RAO) 3 Performance Over Time (referred to as the "point mixing model evaluation") (Section 3 of this appendix, FS Section 5.5)
- Recontamination Potential (referred to as the "grid model evaluation") (Section 4 of this appendix, FS Section 5.4)

This appendix also summarizes the sensitivity and bounding analyses conducted to determine the relative influence of input parameters on the results of the predictive evaluations (Sections 2.3, 3.4, and 4.5 of this appendix).

2 SITE-WIDE PERFORMANCE OVER TIME (BOX MODEL EVALUATION)

The box model evaluation was used to predict spatially-weighted average concentrations (SWAC) for the alternatives from years 0 to 40 post-construction for the four human health risk driver contaminants of concern (COCs):

1. Polychlorinated biphenyls (PCBs)
2. Arsenic
3. Carcinogenic polycyclic aromatic hydrocarbons (cPAHs)
4. Dioxins/furans

Predicted SWACs were then used for the screening of alternatives (Appendix L) and for the detailed and comparative evaluation of the retained alternatives (FS Sections 9 and 10).

The box model evaluation was conducted using a Microsoft Excel spreadsheet-based analytical model that calculates site-wide and sub-area SWACs within the EW. The SWAC for each human health risk driver COC is calculated beginning at year 0 (immediately following construction) and at 5-year intervals through year 40. The site-wide SWAC for each COC is determined at each 5-year interval (e.g., 0, 5, 10, 15, etc.) through a series of calculations that take into account remedial technology and sediment mixing assumptions, which vary across the EW, and incoming sediment characteristics. A sensitivity and bounding evaluation was also conducted, based on range of values for input variables, to determine the effect of uncertainty in the input information on the SWAC calculations.

This section provides a description of input parameters used in the evaluation, including ranges used for sensitivity and bounding (Section 2.1), mathematical basis for the calculations (Section 2.2), sensitivity and bounding analyses for the model results (Section 2.3), and a brief summary of where the model results are used within the FS (Section 2.4). Section 5 of this appendix provides additional considerations regarding uncertainties associated with predicted SWAC values using the box model evaluation.

2.1 Input Information

The box model evaluation utilized several types of input information to estimate SWAC values over the 40-year post-construction time period, as follows:

- Upstream and lateral solids loading and net sedimentation rates (NSRs) within the EW
- Chemistry assumptions for incoming solids
- Post-construction surface sediment concentrations, including dredge residuals thickness and concentrations
- Sediment mixing and underpier exchange assumptions
- Bioavailability of hydrophobic organic contaminants
- Remedial technologies for the remedial alternatives

Development of best estimates (base case) values for each of these input parameters are discussed in detail in FS Sections 5.3.1 through 5.3.5, and summarized in the following subsections. There are uncertainties in the selection of the best estimate (base case) values for the input parameters. In order to evaluate the sensitivity of the box model calculations (SWAC values) to these uncertainties, high and low values of these input parameters were also developed. A discussion of the high and low values for these inputs is also provided in the following subsections, and the sensitivity analysis is provided in Section 2.3 herein.

A summary of the best estimate (base case) and high and low values for each of the input variables is provided in Chart 1. Chart 1 also provides a road-map, in the last column of the chart, to the location where detailed discussion and justification for the values of each parameter can be found within the EW FS.

Chart 1

Summary of Base Case and High and Low Range Values of Variables used in the Box Model Evaluation

Variable	Range of Values used in Sensitivity Analysis			Basis for Range of Values	Road Map to Sections in the FS for Detailed Discussion
	Low	**Base Case**	**High**		
Site-wide NSR (cm/yr)	0.5	1.2	1.8	**Base case**: Estimated as a site-wide area average by assigning areas either 1.6, 0.5, or 0 cm/yr NSRs based on geochronology core data and vessel operations. **Low**: Estimated with the average of the Pb-210 cores with best-fit lines. **High**: Average of high range of values calculated for Cs-137 data for each core where Cs-137 peaks were found.	• Section 2.1.1 herein • FS Sections 5.1.1 and 5.1.2 • FS Figure 5-1
Variable NSR	Three NSRs assigned to different areas with site-wide average net sedimentation equal to 1.2 cm/yr.			Areas assigned either 1.6, 0.5, or 0 cm/yr NSRs based on geochronology core data, vessel operations, and comparison of bathymetric surveys.	
EW Laterals Chemical Concentrations	Low	Base Case	High	Section 2.1.2.1 and Table 1 herein, FS Section 5.3.1, FS Tables 5-3 and 5-4, and FS Appendix B, Part 4.	
Green River Chemical Concentrations	Low	Base Case	High	Section 2.1.2.1 and Table 1 herein, FS Section 5.3.1, FS Tables 5-3 and 5-4, and FS Appendix B, Part 3B.	
Dredge Residuals Thickness - Dredged Areas / Unremediated Islands (cm)	3.1 / 0.6	5.1 / 1.0	7.2 / 1.4	**Base case**: Core-by-core analysis incorporating multiple dredge passes and assuming 5% loss of dredge material. **Low**: Core-by-core analysis incorporating multiple dredge passes and assuming 3% loss of dredge material. **High**: Core-by-core analysis incorporating multiple dredge passes and assuming 7% loss of dredge material.	• Section 2.1.2.1 herein • FS Appendix B, Part 3A
Dredge Residuals Concentration - Dredged Areas / Unremediated Islands (Total PCBs; µg/kg dw)	540 / 470	760 / 640	1280 / 980	**Base case**: Core-by-core analysis incorporating multiple dredge passes. Cores are area-weighted averaged by Thiessen polygon. **Low**: Median value of the core-by-core analysis. **High**: 95% upper confidence limit on the mean (gamma distribution) of the core-by-core analysis.	• Section 2.1.2.1 herein • FS Appendix B, Part 3A
Mixing Depth due to Propwash in Vessel Operation Areas	1[1]	2	3[1]	Vertical mixing depths were variable across the EW in open-water areas as shown in Figure 5-3. For high and low ranges, only open-water areas with best estimate mixing depths equal to 2 feet were varied as part of the sensitivity analysis. Underpier sediments were assumed to be fully mixed by volume for all cases (sensitivity to underpier mixing was evaluated through range in percent exchange). **Base case**: Approximate site-wide average of estimating propwash mixing depth within areas predicted to have mixing depths greater than 0.5 feet, as shown in Figure 5-3. **Low**: Value chosen to be 1 foot lower than the base case in the 2-foot mixing areas shown in Figure 5-3. **High**: Value chosen to be 1 foot higher than the base case, in the 2-foot mixing areas shown in Figure 5-3. This value is not as large as the largest estimated mixing depth (4.7 feet), as that is a conservatively high value (to assign to the entire EW) based on methods used to estimate propwash mixing depths in the SRI[2].	• Section 2.1.4 herein • FS Section 5.1.5 • FS Figure 5-2 • FS Appendix B, Part 2
Percent of EW Open-water Area that is Vertically Mixed Every 5 Years	30%	50%	90%	10-cm biologically active zone mixing is assumed to be the minimum mixing depth in all areas. **Base case**: Approximate percent of the EW area that is either: 1) subject to frequent propwash mixing based on the area of the EW with geochronology cores with Cs-137 peaks or higher correlation Pb-210 data; 2) contains unrecoverable geochronology cores; 3) contains cores without either Cs-137 peaks or Pb-210 correlations; or 4) in areas where cores were not attempted (areas presumed to mix or that were previous dredged). **Low**: Low bound estimated based on areas where NSRs are 0 or 0.5 cm/yr. Although vessels actively navigate 90% of the EW, propeller scour effects from individual vessels create localized effects, so some sediment could remain undisturbed over time. **High**: Approximate percent of the EW that is, or could be, subject to propwash mixing based on vessel operations in each area as documented in the STER[3] and SRI[2]. Areas 1C and 7 are excluded from propwash mixing due to documented lack of current or future planned vessel operations and all other areas are considered propwash areas.	• Section 2.1.5 herein • FS Section 5.3.3

Chart 1

Summary of Base Case and High and Low Range Values of Variables used in the Box Model Evaluation

Variable	Range of Values used in Sensitivity Analysis			Basis for Range of Values	Road Map to Sections in the FS for Detailed Discussion
	Low	Base Case	High		
Percent Exchange Between Underpier and Open-water Sediments Every 5 years	5%	25%	50%	**Base case**: Approximate percent of the pier face length subject to significant propwash impact compared to the total length of the pier face. **Low**: Represents minimal exchange of sediment between open-water and underpier areas. **High**: Represents reasonable high underpier exchange estimate. 100% was not chosen because it is likely that some portion of the underpier areas (even in an extreme case) would not mix every 5 years. Approximate percent of the underpier volume mixed based on a 2-foot mixing depth (low end of predicted range for mixing depth). Average depth of sediments in the underpier areas is approximately 2 feet.	• Section 2.1.6 herein • FS Section 5.3.4
Percent Reduction in Bioavailability of Hydrophobic Organic Contaminants in Underpier Sediments Due to In situ Treatment	50%	70%	90%	**Base case**: Represents bioavailability due to in situ treatment in laboratory and field studies in stable sediment (90%) adjusted downward to account for dilution of AC during mixing and exchange of underpier sediment. **Low**: Represents low estimate of bioavailability reduction due to dilution of AC from mixing and exchange of underpier sediment. **High**: Estimate of the percent reduction in bioavailability due to in situ treatment in laboratory and field studies in stable sediment.	• Section 2.1.7 herein • FS Section 7.2.7.1.1

Notes:
1. High and low range of vertical mixing depths applied to open-water areas where best estimate (base case) vertical mixing depth was equal to 2 feet.
2. *Final Supplemental Remedial Investigation Report* (SRI; Windward and Anchor QEA 2014).
3. *Final Sediment Transport Evaluation Report* (STER; Anchor QEA and Coast & Harbor Engineering 2012).

µg/kg – micrograms per kilogram
AC – activated carbon
cm/yr – centimeters per year
Cs-137 – cesium-137
dw – dry weight
EW – East Waterway
FS – Feasibility Study
NSR – net sedimentation rate
Pb-210 – lead-210
PCB – polychlorinated biphenyl

2.1.1 Solids Loads and Net Sedimentation Rate

Representative site-wide average NSR from all solids sources to the EW (upstream and EW lateral inputs) were estimated using site-specific geochronology core data and delineation of vessel operation areas within the EW (see Sections 3.4.2 and 3.3, respectively, of the *Final Supplemental Remedial Investigation Report* (SRI); Windward and Anchor QEA 2014). Additional evaluation of the site average NSR was conducted following approval of the SRI to explicitly include lead-210 (Pb-210) data in the calculation, and to take into account areas of the EW regularly affected by vessel operations where net sedimentation is likely close to 0. These additional evaluations are documented in detail in FS Sections 5.1.1 and 5.1.2 and Figure 5-1. Based on this work, the base case value for site-wide average NSR for the EW was estimated to be 1.2 centimeters per year (cm/yr). For the purposes of the box model evaluation, the representative NSR was assumed to be a single constant value throughout the EW, recognizing that actual sediment accumulation may vary considerably on location basis (both above and below 1.2 cm/yr) due to propwash effects associated with vessel operations within the waterway.

The high range value of site-wide NSR was 1.8 cm/yr, which is the average of the high range of NSRs calculated from cesium-137 (Cs-137) data from recovered geochronology cores (see Table 3-3 in the EW SRI; Windward and Anchor QEA 2014). The low range value for NSR was 0.5 cm/yr, which is the average of the NSRs estimated using Pb-210 data (see Table 3-3 in the EW SRI). In addition to low and high values of site-wide NSRs, the sensitivity analysis for the box model evaluation included a simulation that used variable NSRs within the EW, as shown in Figure 5-1 (as opposed to a single value for the entire site).

The proportion of incoming sediment attributed to upstream solids sources (i.e., the Green River, Lower Duwamish Waterway [LDW] bed sediments, and LDW lateral inputs) and EW lateral sources was estimated using the results of the LDW sediment transport model (QEA 2008), the updated EW hydrodynamic model (Anchor QEA and Coast & Harbor Engineering 2012), and deposition of sediments from EW lateral sources in the EW estimated from particle tracking model (PTM) results (see FS Appendix B). The estimated amount of solids input to the EW (by source), and the amount predicted to deposit within the EW are shown in Table 1.

2.1.2 Chemistry Assumptions

Chemistry assumptions for use in the box model for the four human health risk driver COCs were developed for incoming solids (i.e., upstream sources [the Green River, LDW bed sediments, and LDW lateral sources] and EW lateral sources), for existing conditions for in situ bed sediments, and for post-construction concentrations in remediation areas (i.e., bed replacement values and dredge residuals concentrations, which vary according to the remedial technology used for the alternatives).

2.1.2.1 Incoming Solids

Chemistry assumptions for incoming solids (upstream sources and EW lateral sources) were estimated from available empirical data as described in FS Section 5.3.1 and Appendix B, Parts 3B and 4. The best estimate (base case), high bounding, and low bounding concentrations from all sources to the EW are listed in FS Tables 5-3 and 5-5. The average net incoming concentrations considering both upstream and lateral sources for total PCBs are presented in Chart 2.

Chart 2

Net Incoming Solids Concentrations[1] Considering Upstream and Lateral Sources

Scenario		PCBs Concentration (µg/kg dw)
Current Case (years 0 to 10 post-construction)	Best Estimate	46
	Low Bounding	8.0
	High Bounding	86
Future Case[2] (years 11 to 40 post-construction)	Best Estimate	45
	Low Bounding	7.7
	High Bounding	85

Notes:
1. See FS Table 5-5 for net incoming concentrations for all upstream sources.
2. Future conditions are based on actions to reduce lateral loads such as CSO control where required to meet NPDES permit conditions and source control in storm drain basins. Upstream incoming solids were not modified for the future case because of uncertainty in the timeframe and scope of those controls, and because they are likely to be captured by the low bounding concentration estimate.

µg/kg – micrograms per kilogram
CSO – combined sewer overflow
dw – dry weight
FS – Feasibility Study
LDW – Lower Duwamish Waterway
NPDES – National Pollutant Discharge Elimination System
PCB – polychlorinated biphenyl

2.1.2.2 Dredge Residuals

Generated dredge residuals are contaminated sediments that are resuspended from the seabed during dredging activities and settle back onto the remediated surface or adjacent unremediated surfaces. Methods for estimating chemistry associated with dredge residuals and dredge residuals thickness are discussed in detail in FS Appendix B, Part 3A (Section 2).

Concentrations for the best estimate (base case) dredge residuals were estimated to be 640 micrograms per kilogram (μg/kg) dry weight (dw) for total PCBs, 490 μg toxic equivalent (TEQ)/kg dw for cPAHs, 10 milligrams per kilogram (mg/kg) dw for arsenic, and 17 nanograms (ng) TEQ/kg dw for dioxin/furans. There are two separate thicknesses of dredge residuals used in the box model calculations; one thickness that is applied over areas that are being actively dredged, and another thickness that is applied over adjacent areas where removal is not occurring. Base case assumptions for dredge residuals thickness are estimated to be 5.1 cm for all dredged areas and 1.0 cm in areas adjacent to dredging areas.

High and low ranges of dredge residuals for PCBs used in the sensitivity evaluation were developed by varying both the dredge residuals concentration and dredge residuals thickness. High and low estimates for dredge residuals chemistry (PCBs) and thickness are shown in Chart 1.

2.1.2.3 Post-construction Concentrations

Methods for estimating post-construction (i.e., bed replacement) values associated with each remedial technology are presented in Table 2 and described in detail in FS Appendix B, Part 3A (Sections 2.4 and 3).

Chemical concentrations for existing (in situ) bed sediments used for the no action alternative and designated no action and monitored natural recovery (MNR) areas within remedial alternatives were determined by interpolating existing surface sediment and shallow subsurface sediment data using Thiessen polygons, as discussed in FS Section 2.

2.1.3 Vertical Mixing Depths

Vertical mixing depth estimates in open-water areas for the box model are spatially variable over the EW and were developed based on predicted scour depths in the EW due to propwash. The predicted scour depths are discussed in FS Section 5.1.5 and Appendix B, Part 2. The justification for the range of vertical mixing depths used in the box model evaluation are discussed in FS Section 5.3.3 and illustrated in FS Figure 5-2. The best estimate (base case) vertical mixing depths used in the box model evaluation range from 2 feet in highly energetic propwash areas to 10 cm in areas impacted by bioturbation only (areas with no vessel operations). Underpier areas are assumed to be full-mixed by volume as the average sediment depth is 2 feet.

The high range value for vertical mixing was set to 3 feet in highly energetic propwash areas, and the low range value vertical mixing was set to 1 foot in these areas. These values were chosen based on the range of propwash scour depths calculated in these areas (see FS Figure 5-2 and the SRI [Anchor QEA and Coast & Harbor Engineering 2012]) and to ensure that there was an equal variation about the base case (1 foot higher and 1 foot lower).

2.1.4 Percent of East Waterway Study Area that is Mixed

In addition to vertical mixing assumptions, the percent of the surface area within the EW that is mixed was also included as a variable in the box model because propwash mixing is not expected to cover the entire waterway. The base case value for percent area mixed was set at 50% of the surface area of the EW (both open-water and underpier areas) every 5 years. Justification for selection of 50% area mixing within the EW is provided in FS Section 5.3.3 considering both vessel scour predictions and geochonological data.

The high range value for percent of EW area mixed was set to 90%, which represents the percent of the EW area that is subject to vessel operations and, therefore, has potential for propwash erosion. This includes all vessel operation areas shown in FS Figure 5-1, except for Areas 1C and 7, where no vessel operations are currently occurring or are planned to occur in the future. The low range value for percent of EW area mixed was set to 30%, which represents the percent of the EW area where NSRs were estimated from geochronology cores to be low (0 to 0.5 cm/yr), see FS Figure 5-1. Propwash erosion results in lower NSR estimates, therefore, areas of the EW with lower net sedimentation are most likely to be subject to significant propwash erosion[1].

2.1.5 Percent Exchange

Vessel scour by propwash in open-water and underpier areas results in exchange of sediments between those two areas due to resuspension and deposition of bed sediments. In order to account for this mechanism in the box model evaluation, an exchange of sediments between the open-water and underpier areas was programmed into the model. This physical process was simulated in the model by including a volume exchange calculation in the box model that exchanges 25% of the total volume of sediment located in the underpier areas with the same volume of sediment from the open-water areas within the EW (with each of their associated chemistries). The box model evenly distributes the exchanged underpier sediments throughout the open-water areas; this is a conservative assumption because it is more likely that these sediments settle nearer to piers than the middle of the navigation channel, which would result in locally higher concentrations nearer to outfalls compared to the SWAC value. Justification for selection of 25% exchange within the EW is provided in FS Section 5.3.4.

The high range value for percent of underpier sediments exchanged with open water was set to 50%, which is considered a reasonable high bound and is equivalent to the exchange of 1 foot of sediment across the entire underpier area (see FS Figure 5-3). The low range value for percent of underpier sediments exchanged was set to 5%, which is the approximate volume of underpier sediments adjacent to vessel operational Area 1A-4 (shown in FS Figure 5-1) that has been assigned a NSR of 0 due to impacts from propwash.

2.1.6 Bioavailability of Hydrophobic Organic Contaminants

The percent reduction in bioavailability of hydrophobic organic contaminants (including total PCBs) in underpier sediments due to in situ treatment was included as a parameter in the box model evaluation for remedial alternatives that included in situ treatment. The best

[1] In the SRI, the EW was determined to be net depositional (site-wide average) and that near-bed current velocities were not large enough to cause erosion of bed sediments. Therefore, areas within the EW found to have lower or zero net sedimentation are assumed to be subject to erosion by propwash (see FS Section 5.1).

estimate value for reduction in bioavailability (70%) was determined through review of literature and pilot study results and consideration of stability of the material, and is discussed in FS Section 7.2.7.1.1.

High and low values for this parameter were used to examine the sensitivity of the box model calculations to choice of bioavailability. The high range value for reduction in bioavailability was based on laboratory and field studies, and assumes that sediments will be largely stable (90%). The low range value for bioavailability was estimated assuming that effectiveness is further diminished by loss of stability through scour and transport mechanisms in the EW, which lowers activated carbon (i.e., in situ treatment material) concentrations in sediments to less effective levels (50%).

2.1.7 Remedial Technology Assignments

The area of each remedial technology for the screening alternatives is presented in Table 3 herein and depicted in FS Appendix L, Figures 2-1 through 2-16. Table 2 herein provides the post-construction concentrations associated with each remedial technology and screening alternative.

Each remedial technology is represented in the box model by a vertical bed layer model, which consisted of post-construction surface concentrations, dredge residuals layer, enhanced natural recovery (ENR) layer, backfill layer, residuals management cover (RMC) layer, and/or cap material layer, depending on remedial technology. The vertical layers associated with each remedial technology are summarized in Chart 3 and depicted in Figures 1a through 1j.

Chart 3
Remedial Technologies and Associated Actions for Box Model Evaluation

Technology	Model Components (see Figures 1a – 1h herein)			
	Removal	Placement Material	Dredge Residuals Layer	Vertical Sediment Bed Layer Figure (s)
Removal	X	Residuals management cover	X	1a and 1b
Removal and backfill to existing grade	X	Backfill	X	1c
No action (open-water interior unremediated islands)		Residuals management cover	X	1d
No action (Junction Reach and Northern end of EW)		None		1e
MNR		None	X	1f
ENR		ENR sand	X	1g
Partial removal and cap	X	Multi-layer cap with armor	X	1h and 1i
ENR-nav		ENR sand	X	1j
In situ treatment (underpier)		In situ treatment material	X[a]	None – underpier sediment is modeled as a single volume of material

Notes:
a. In situ treatment was placed on a residuals layer in areas that included diver-assisted hydraulic dredging prior to placement of in situ treatment.
ENR – enhanced natural recovery
MNR – monitored natural recovery
EW – East Waterway

2.2 Site-wide SWAC Calculations

The box model evaluation is used to calculate site-wide surface sediment SWAC over time for the four human health risk COCs for the screening alternatives based on the model inputs described above.

This section summarizes the specific mathematical calculations that were conducted as part of the box model evaluation to calculate site-wide SWAC values for all screening alternatives at year 0, directly following construction, and years 5 through 40, post-construction. Justification for the methodology for calculating site-wide SWAC values is discussed in FS Section 5.3.

2.2.1 Definition of East Waterway Sub-areas

The EW is divided up into sub-areas that represent remedial technologies applied within the EW for each alternative. These remedial technology sub-areas are further sub-divided based on vertical mixing depth areas (see FS Figure 5-2). This results in definition of each sub-area within the EW that has a unique remedial technology and vertical mixing depth. Figure 2 shows an example map to illustrate what these sub-areas look like, developed for Alternative 1A(12). All underpier areas are treated as one sub-area for the purpose of these calculations.

2.2.2 Total Incoming Solids Chemistry

A value of 1.2 cm was used for the current condition annual NSR for the EW. The NSR for the future condition was adjusted downward to 1.198 cm to account for the predicted reduction of input from additional source control actions that are expected to take place in the next 10 years that will reduce loads from EW storm drains (SDs) and combined sewer overflows (CSOs).

The average incoming solids concentrations were calculated by calculating the weighted average by mass of the five deposited solids loads to the EW from each of the source locations, which are as follows:

1. Green River
2. LDW bed sediments
3. LDW lateral inputs
4. EW SDs
5. EW CSOs

Equation 1 was used to find the average incoming solids concentrations to the EW from the five source locations.

$$Average\ Incoming\ Solids\ Concentration = \frac{\sum_{i=1}^{5}[Input_i Load * Input_i Concentration]}{\sum_{i=1}^{5} Input_i Load} \tag{1}$$

where:

$Input_i$ Load	=	deposited sediment load from each of the five input locations listed above
$Input_i$ Concentration	=	chemical concentration for each of the COCs associated with the identified solids loads from the five input locations above

Values for average incoming sediment concentrations used for the box model evaluation are provided in FS Section 5, Table 5-5.

2.2.3 Year 0 SWAC

Year 0 SWAC concentrations were calculated based on delineation of remedial technologies and corresponding existing (in situ) sediment chemistry or bed replacement chemistry values for each alternative. Equation 2 was used to calculate year 0 post-construction SWAC values.

$$SWAC_0 = \frac{\sum_{m=1}^{a}[C_{m0}A_m]}{\sum_{m=1}^{a}A_m} \tag{2}$$

where:

$SWAC_0$	=	SWAC at year 0
a	=	Number of unique sub-areas (combinations of remedial technologies and vertical mixing depths, including underpier areas)
A_m	=	Area of each individual sub-area
C_{m0}	=	Surface concentration of year 0 of each individual sub-area

2.2.4 Concentrations of Vertically Mixed Open-water Sub-areas

At year 0, each open-water sub-area is characterized by a vertical bed layer model (thickness and concentration of sediment layers) based on remedial technology as shown in Figures 1a through 1j. At year 5, an additional sediment layer representing deposition of incoming solids is included on top of the year 0 sediment layers. Following deposition, the individual sediment layers shown in Figures 1a through 1j are mixed vertically over the vertical mixing depth for 50% of each sub-area. The other 50% of each sub-area is vertically mixed based on the bioturbation depth (10 cm). This simulates that only 50% of the open-water area of the EW is mixed by propwash within the 5-year timeframe.

The general formulas used to calculate the vertically mixed surface sediment concentration for each sub-area at year 5 post-remediation are presented in Equations 3 and 4. These general formulas are applicable to all open-water remedial technologies, consistent with vertical bed layer models and vertical mixing processes shown in Figures 1a through 1j.

$$C_{5i(a)} = \left[\frac{(C_{depc} \times T_{ydc}) + (C_{sc(a)} \times T_{sc(a)}) + \left(C_{br(a)} \times T_{br(a)}\right) + (C_{r(a)} \times T_{r(a)})}{T_{mix(a)}} \right] \quad (3)$$

$$T_{br(a)} = T_{mix(a)} - T_{ydc} - T_{sc(a)} \quad (4)$$

where:

$C_{5i(a)}$ = vertically mixed sediment concentration for sub-area "a" at year 5 prior to exchange (called "intermediate value" in Figures 1a through 1j)

C_{depc} = concentration of net deposition sediments (current conditions)

T_{ydc} = thickness of net deposition sediments over 5-year timeframe (current conditions)

$C_{sc(a)}$ = concentration of sand cover layer for sub-area "a"

$T_{sc(a)}$ = thickness of sand cover layer for sub-area "a"

$C_{br(a)}$ = concentration of bed replacement layer sediments for sub-area "a"

$T_{br(a)}$[2] = thickness of bed replacement layer sediments captured by the vertical mixing depth ($T_{mix(a)}$) for sub-area "a"

$T_{mix(a)}$ = mixing depth for sub-area "a" (mixing by propwash)

Once the initial vertical mixing of each sub-area is conducted (either to the full mixing depth or the bioturbation depth), exchange with underpier sediments is incorporated into the sub-area sediment concentrations. The exchange calculations between open-water and underpier sediments simulates mixing of bed sediments between the underpier and open-water areas

[2] This variable is not defined in the vertical bed models shown in Figures 1a through 1j.

due to re-suspension from the bed by propwash[3]. This calculation is performed for each sub-area, as shown in Equations 5 and 6 and illustrated in Figures 1a through 1j.

$$C_{5f(a)} = \left[\frac{(C_{5i(a)} \times T_{5i(a)}) + (C_{5ex} \times T_{5ex})}{T_{mix(a)}} \right] \tag{5}$$

$$T_{5i(a)} = T_{mix(a)} - T_{5ex} \tag{6}$$

where:

$C_{5f(a)}$	=	vertically mixed sediment concentration for sub-area "a" at year 5 following exchange (called "final value" in Figures 1a through 1j)
$T_{5i(a)}$[4]	=	thickness of vertically mixed sediment layer prior to exchange at year 5 captured by the vertical mixing depth ($T_{mix(a)}$) for sub-area "a"
C_{5ex}	=	concentration of under pier sediments following mixing at year 5, but prior to exchange with open-water sediments (see Section 2.3.5)
T_{5ex}	=	thickness of volume of under pier sediments exchanged at year 5; this is estimated as the volume of underpier sediments to be exchanged (25% of total volume) spread evenly over the entire surface area of the open-water areas
$T_{mix(a)}$	=	mixing depth for sub-area "a" (mixing by propwash)

The general formulas for year 5 (Equations 3 through 6) are conceptually the same for years 10 through 40 (Equations 7 through 10); however, there are fewer distinct sediment layers present following the first vertical mixing event in year 5. The general formulas used to calculate the vertically mixed surface sediment concentration for each open-water sub-area for years 10 through 40 prior to exchange are presented in Equations 7 and 8 and illustrated in Figures 1a through 1j.

$$C_{Ni(a)} = \left[\frac{(C_{depc} \times T_{ydc}) + (C_{(N-5)f(a)} \times T_{(N-5)f(a)})}{T_{mix(a)}} \right] \tag{7}$$

[3] The rationale for 25% exchange estimate between open-water and underpier areas is provided in FS Section 5.3.4.

[4] This variable is not defined in the vertical bed models shown in Figures 1a through 1j.

$$T_{(N-5)f(a)} = T_{mix(a)} - T_{ydc} \tag{8}$$

where:

$C_{Ni(a)}$	=	vertically mixed sediment concentration for sub-area "a" at year N prior to exchange (called "intermediate value" in Figures 1a through 1j)
$C_{(N-5)f(a)}$	=	final vertically mixed concentration of sediments for prior 5-year interval (year=N-5) for sub-area "a" after exchange taken into account (called "final value" in Figures 1a through 1j)
C_{depc}	=	concentration of net deposition sediments (current conditions for year 10, future conditions for years greater than 10)
T_{ydc}	=	thickness of net deposition sediments over 5-year time period (current conditions for year 10, future conditions for years greater than 10)
$T_{(N-5)f(a)}$[5]	=	thickness of the vertically mixed layer from prior 5-year interval (year=N-5) captured by the vertical mixing depth ($T_{mix(a)}$) for sub-area "a"
$T_{mix(a)}$	=	mixing depth for sub-area "a" (mixing by propwash)

For years 10 through 40 (as with year 5), once the initial vertical mixing of each sub-area is conducted (either to the full mixing depth or the bioturbation depth), exchange with underpier sediments is incorporated into the sub-area sediment concentrations. This is done mathematically for each sub-area, as shown in Equations 9 and 10 and illustrated in Figures 1a through 1j.

$$C_{Nf(a)} = \left[\frac{(C_{Ni(a)} \times T_{Ni(a)}) + (C_{Nex} \times T_{Nex})}{T_{mix(a)}} \right] \tag{9}$$

$$T_{Ni(a)} = T_{mix(a)} - T_{Nex} \tag{10}$$

where:

$C_{Nf(a)}$	=	vertically mixed sediment concentration for sub-area "a" at year N following exchange (called "final value" in Figures 1a through 1j)

[5] This variable is not defined in the vertical bed models shown in Figures 1a through 1j.

$T_{Ni(a)}$[6] = thickness of vertically mixed sediment layer prior to exchange at year N captured by the vertical mixing depth ($T_{mix(a)}$) for sub-area "a"

C_{Nex} = concentration of underpier sediments following mixing at year N, but prior to exchange with open-water sediments (see Section 2.3.5)

T_{Nex} = thickness of volume of underpier sediments exchanged at year N; this is estimated as the volume of underpier sediments to be exchanged (25% of total volume) spread evenly over the entire surface area of the open-water areas

$T_{mix(a)}$ = mixing depth for sub-area "a" (mixing by propwash)

2.2.5 Concentrations of Vertically Mixed Underpier Areas

The underpier areas are represented as a single area within the box model. At year 0, the surface concentration of the underpier area is calculated as a SWAC based on the area and concentration for each technology sub-area (Table 2; Equation 1). For years 5 through 40, an additional sediment volume representing deposition of incoming solids over the previous 5-year time period is added to the in situ underpier sediment volume; and the entire volume of material is mixed to calculate a volume-weighted average concentration. The rationale for assumption of complete vertical mixing of underpier sediments is discussed in FS Section 5.3.4.

Equations 11 through 13 show the calculation of underpier sediment concentrations at years 5 to 40 in the box model (prior to exchange with open-water areas).

$$C_{ex\_N} = C_{UP\_Ni} = \left[\frac{(C_{UP(N-5)f} \times V_{UP(N-5)f}) + (C_{depc} \times V_{depc})}{V_{UP\_Ni}} \right] \tag{11}$$

$$V_{UP\_Ni} = V_{UP(N-5)f} + (SA_{UP} \times T_{ydc}) \tag{12}$$

$$V_{depc} = SA_{UP} \times T_{ydc} \tag{13}$$

where:

C_{ex_N}, C_{UP_Ni} = concentration of underpier sediments at year N prior to exchange with open-water areas ("intermediate" concentration); this is the

[6] This variable is not defined in the vertical bed models shown in Figures 1a through 1j.

concentration of underpier sediments exchanged with open-water areas (C_{ex} in Figures 1a through 1j)

$C_{UP\_(N-5)f}$ = final concentration of underpier sediments of prior 5-year interval (where N is current year) after exchange with open-water areas ("final" concentration)

$V_{UP(N-5)f}$ = total volume of underpier sediments of prior 5-year interval (where N is current year) after exchange with open-water areas

V_{UP_Ni} = total volume of underpier sediments at year N (including volume of deposited sediments) prior to exchange with open-water areas

C_{depc} = concentration of net deposition sediments

T_{ydc} = thickness of net deposition sediments

SA_{UP} = surface area of underpier areas where sediment is deposited over the armor rock (see FS Section 2.6)

V_{depc} = volume of deposited sediments in underpier areas calculated using Equation 13

For years 5 through 40, once the intermediate concentration of underpier sediments is calculated, exchange with open-water sediments is incorporated into the underpier sediment concentrations. First, 25% of the underpier sediment volume (V_{UP_Ni}) with a concentration equal to C_{ex_N} (concentration of underpier sediments prior to exchange) is evenly deposited over each open-water sub-area. Then, the exchanged underpier sediment is mixed vertically within each open-water sub-area as discussed in Section 2.3.4 to calculate final post-exchange concentrations in each open-water sub-area. The SWAC of the open-water sub-areas (using these post-exchange concentrations) is then calculated. Finally, a volume of open-water sediments equal to 25% of the underpier sediment volume with a concentration equal to the pre-exchange SWAC of the open-water areas is added to the underpier sediments to complete the exchange. The final post-exchange concentration of the underpier sediments is calculated by averaging concentrations of the initially mixed underpier sediments with the exchanged sediment from the open-water areas (volume-weighted average). This is shown mathematically in Equation 14.

$$C_{UP\_Nf} = \left[\frac{(C_{UP\_Ni} \times V_{UP\_Ni}) + (C_{SWAC\_OW\_Nf} \times V_{ex})}{V_{UP\_Ni} + V_{ex}} \right] \tag{14}$$

where:

C_{UP_Nf} = concentration of underpier sediments at year N following to exchange with open-water areas ("final" concentration)

C_{UP_Ni} = concentration of underpier sediments at year N prior to exchange with open-water ("intermediate" concentration)

$C_{SWAC\_OW\_Nf}$ = SWAC concentration of open-water sediments at year N after exchange with underpier sediments

V_{UP_Ni} = total volume of underpier sediments at year N (including volume of deposited sediments) prior to exchange with open-water areas

V_{ex} = volume of open-water sediment exchanged with underpier areas; 25% of V_{UP_Ni}

2.2.6 Site-wide SWAC (Years 5 to 40)

For each 5-year interval post-construction from years 5 to 40, site-wide SWACs are calculated using the post-exchange fully-mixed surface sediment concentrations for each open-water sub-area and the underpier area using Equation 15.

$$SWAC_{\mathrm{N}} = \frac{\sum_{m=1}^{\mathrm{a}}[C_{m\mathrm{N}}A_m]}{\sum_{m=1}^{\mathrm{a}} A_m} \tag{15}$$

where:

$SWAC_N$ = site-wide EW SWAC for year N, where N is from 5 to 40 years

a = number of unique sub-areas (combinations of remedial technologies and vertical mixing depths, including underpier areas)

A_m = area of each individual sub-area

C_{mN} = surface concentration at year N of each individual sub-area following deposition of incoming solids, vertical mixing, and exchange with underpier

2.3 Sensitivity and Bounding Evaluation

The effects of variability and uncertainty in the physical processes and chemical concentrations in the EW on estimates of site-wide SWACs were evaluated with a sensitivity and bounding analysis. The sensitivity evaluation was completed to examine the relative impact of individual variables on the predicted site-wide SWACs. The bounding evaluation was used to examine the potential range in predicted SWACs based on combinations of specific input variables that were found to significantly impact the SWACs in the sensitivity evaluation.

The sensitivity and bounding evaluations were conducted on Alternatives 1A(12) and 2B(12) (see FS Appendix L, Figures 2-1 and 2-5) using a range of input variable assumptions (see Section 2.3.1 below for more detail). The sensitivity and bounding calculations were conducted using two remedial alternatives so that the analysis could be applied to different remedial technology combinations. Alternative 1A(12) was selected because it relies on natural recovery more than the other alternatives. Alternative 2B(12) was selected because it is representative of the majority of the remedial alternatives that rely more heavily on removal.

Sensitivity and bounding analyses were conducted for total PCBs only. Total PCBs is the COC that contributes the most to site risk for RAOs 1 (human health seafood consumption), 3 (benthic invertebrates), and 4 (ecological risk), and is distributed throughout the waterway. For this modeling analysis, PCBs effectively demonstrate the trends that can be expected for other COCs.

2.3.1 Variables Used in Evaluation

The sensitivity of the SWAC values calculated using the box model evaluation were analyzed for the following input variables to the box model:

- Value of the average NSR for the EW (single value applied across the site)
- Use of variable NSR in the EW
- Vertical mixing depth in the highly energetic propwash mixing areas
- Percent of the EW Study Area that was allowed to fully mix (vertically)
- Percent of underpier sediment volume that is exchanged with open-water areas
- Bioavailability of hydrophobic organic contaminants (including total PCBs) in underpier sediments due to in situ treatment

- Dredge residuals layer thickness and concentrations and replacement values
- Green River solids and chemistry[7]
- EW lateral solids and chemistry

The range of values for each variable used in the sensitivity and bounding analysis are discussed in Section 2.1 above and summarized in Chart 1.

2.3.2 Sensitivity Analysis

A list of sensitivity scenarios is provided in Table 4; 18 different scenarios for Alternative 1A(12) and 20 different scenarios for Alternative 2B(12) were evaluated for total PCBs. Alternative 1A(12) only has 18 scenarios because it does not have underpier in situ treatment, and therefore does not have sensitivity parameters for bioavailability. Table 2 herein provides initial surface sediment chemistry for total PCBs by remedial alternative (for the best-estimate dredging residuals and replacement value assumptions), and FS Table 5-3 provides chemistry assumptions for incoming solids.

The total PCB SWAC values over time calculated using the box model for each of the sensitivity scenarios listed in Table 4 were compared to each other numerically and graphically (see Table 5 and Figures 3a through 4b). Figures 3a and 4a plot the estimated SWAC values from year 0 to year 40 for each of the sensitivity analysis scenarios for Alternatives 1A(12) and 2B(12), respectively. Figures 3b and 4b show the comparative percent change in SWAC value for each sensitivity scenario compared to the base case scenario for Alternatives 1A(12) and 2B(12), respectively at years 10 and 30 post-construction. The comparative changes shown in Figures 3b and 4b were calculated by normalizing the SWAC values calculated for each sensitivity scenario at years 10 and 30 post-construction by the SWAC values calculated for the base case scenario at those same years.

2.3.2.1 Alternative 1A(12)

For Alternative 1A(12), the range in inputs for underpier exchange, NSR, and Green River concentration had a relatively high degree of sensitivity (i.e., resulted in greater than 10%

[7] For upstream chemistry the LDW lateral sources and LDW bed sediments inputs are not changed for the sensitivity analysis.

change in SWAC), and the other parameters (residuals thickness, residuals concentration, mixing depth, area mixed, and concentrations in lateral load) showed a low degree of sensitivity (Figures 3a and 3b).

Underpier exchange was the most sensitive parameter 0 to 10 years following construction, but was not a very sensitive parameter in the long-term. The model results predict that more underpier exchange would result in a higher temporary increase in site-wide SWAC following construction, due to the distribution of higher concentration underpier sediments into the larger, mostly remediated open-water areas. Less underpier exchange reduces the site-wide SWAC because the higher concentration sediments in the underpier remain localized.

The two parameters that are the most sensitive in the long-term are range in inputs for NSR and the concentrations of Green River solids. These two parameters are also the second and third most sensitive parameters 0 to 10 years following construction (after underpier exchange), and are therefore the most influential parameters affecting the box model results. Moreover, the two parameters are related because 99% of the sediment deposited in the EW originates from the Green River upstream of the LDW (Table 1).

A higher NSR reduces the site-wide SWAC by reducing the time needed for the site to equilibrate to net incoming concentrations (i.e., increases the rate of natural recovery). A lower NSR increases the site-wide SWAC by increasing the time needed for the site to equilibrate to net incoming concentrations (i.e., decreases the rate of natural recovery). Use of a variable NSR within the EW (based on FS Figure 5-1) did not have any appreciable effect on the SWAC predictions compared to best estimate calculations for any years (see Figure 3a).

In the very long term (i.e., 30 years post-construction and beyond), Green River chemistry is the primary controlling parameter, because it is the primary determinant of the concentration the site will equilibrate to (i.e., the EW net incoming sediment concentrations). In the long-term, higher Green River concentrations will result in higher site-wide SWACs, and lower Green River concentrations will result in lower site-wide SWACs.

2.3.2.2 Alternative 2B(12)

Compared to Alternative 1A(12), Alternative 2B(12) relies less on natural recovery and more on in situ treatment (Alternative 1A(12) uses MNR in underpier areas, and

Alternative 2B(12) used in situ treatment in underpier areas). In addition, Alternative 2B(12) relies on more removal (Alternative 1A(12) uses some ENR-nav in the navigation channel, and Alternative 2B(12) used removal). As a result, Alternatives 2B(12) is less sensitive to the range in inputs for NSR and underpier exchange than Alternative 1A(12), and more sensitive to the range in inputs for Green River concentrations. Alternative 2B(12) also has a high degree of sensitivity to the range in inputs for percent reduction in bioavailability due to in situ treatment. Consistent with Alternative 1A(12), the impact of the other parameters (i.e., residuals thickness, residuals concentration, mixing depth, area mixed, and concentrations in lateral load) showed a low degree of sensitivity (Figure 4a and 4b).

Percent reduction in bioavailability due to in situ treatment was the most sensitive parameter 0 to 10 years following construction, but was less sensitive in the long term. If in situ treatment is more effective at reducing bioavailability, then site-wide SWACs are predicted to be effectively lower, and if in situ treatment is less effective at reducing bioavailability, then site-wide SWACs are predicted to be higher. FS Section 7.2.7.1 describes the in situ treatment effectiveness estimates based on relevant case studies and guidance.

Similar to Alternative 1A(12), Green River chemistry is the primary controlling parameter in the long term, because it is the primary determinant of the concentration the site will equilibrate to. The effect of the range in inputs for Green River chemistry is higher for Alternative 2B(12) compared to Alternative 1A(12) because site-wide SWACs are lower following construction for Alternative 2B(12) (largely due to the change in remediation technology in underpier areas), and therefore it equilibrates more rapidly to net incoming sediment concentrations.

For Alternative 2B(12), the greatest effects to predicted SWAC values are associated with the Green River chemistry (up to 45%) and NSR (up to 15%). The range in inputs for all other variables result in less than 10% change from the base case SWAC values. The predicted SWAC values for Alternative 2B(12) are not as sensitive to the range in inputs for underpier exchange as Alternative 1A(12) because Alternative 2B(12) has active remedial technology in underpier sediments, which results in a lower initial concentration of underpier sediments for Alternative 2B(12).

Residual inputs have more effect on SWAC predictions for Alternative 2B(12); this is because of the combined effect of lower year 0 SWAC (related to active remediation under piers) and more removal in open-water areas. With lower year 0 SWAC and more removal, the site is more influenced by the higher concentrations of residuals when vertical mixing takes place. Also because of the lower year 0 SWAC in Alternative 2B(12), the NSR inputs have less of an influence compared to Alternative 1A(12). As with Alternative 1A(12), use of a variable NSR within the EW (based on FS Figure 5-1) did not have any appreciable impact on the SWAC calculations for any years (see Figure 4a).

2.3.2.3 Summary

Using the combined results for both Alternative 1A(12) and Alternative 2A(12), a summary of the sensitivity analysis by parameter is provided below:

- The range in inputs for Green River chemistry can change predicted SWAC values by up to 25% through year 10 post-construction, and up to 45% by year 30 post-construction. Green River chemistry has greater effect on alternatives with more active remediation and less reliance on natural recovery.
- The range in inputs for NSR can change predicted SWAC values by up to 15% through year 10 post-construction, and up to 35% by year 30 post-construction. NSR has a greater effect on alternatives with more reliance on natural recovery.
- The range in inputs for underpier exchange can change predicted SWAC values by up to 20% at year 10, but its influence drops off to below 10% by year 30. Underpier exchange has more effect on alternatives with MNR in the underpier area.
- The range in inputs for the percent reduction in bioavailability due to in situ treatment can change predicted SWAC values by up to 30% at year 10, but its influence is reduced to up to 20% by year 30. This parameter only effects alternatives that employ in situ treatment.
- The range in inputs for all other parameters effect predicted SWAC values by 10% or less.

2.3.3 Bounding Analysis

The results of the sensitivity analysis were used to develop scenarios (combinations of input parameter values) that result in the lowest and highest SWAC predictions for Alternatives 1A(12) and 2B(12). This bounding analysis was done to quantify the maximum uncertainty in predicted SWAC values from the box model evaluation for all remedial alternatives. The lowest and highest bounding scenarios are determined using results of the sensitivity analysis for Alternatives 1A(12) and 2B(12) that showed which parameters caused the SWAC to increase or decrease (Figures 3b and 4b).

For Alternative 1A(12), using Figure 3b, the following conclusions were made to establish the highest and lowest bounds:

- **NSR and Vertical Mixing Depth[8]:** Decreasing the value of these parameters result in a higher predicted SWAC at years 10 and 30. Therefore the low range values were used for the highest bound scenario and the high range values were used for the lowest bound scenario.
- **Residual Thickness, Residual Concentration, Lateral Concentrations, and Green River Concentrations:** Decreasing the value of these parameters results in a lower predicted SWAC at years 10 and 30. Therefore, the low range values were used for the lowest bound scenario and the high range values were used for the highest bound scenario.
- **Area Mixed:** The effect on the SWAC from this parameter is different at years 10 and 30. Because the box model evaluation was developed to look at effectiveness over the long term, the effect at year 30 was used to determine bounding scenarios. At year 30, decreasing the value of this parameter decreases the predicted SWAC value. Therefore, the low range value was used for the lowest bound scenario and the high range value was used for the highest bound scenario.
- **Underpier Exchange:** The effect on the SWAC from this parameter is different at years 10 and 30. At year 30, both decreasing and increasing this parameter results in a lower predicted SWAC value. At year 5, decreasing the value of this parameter reduces the predicted SWAC, and increasing the value increases the predicted SWAC, so the effect from year 5 was used to determine bounding scenarios. The low input value was used for the lowest bound scenario and the high input value was used for the highest bound scenario.

[8] The shallower mixing depth results in a higher concentration post-construction because of reduced dilution of dredge residuals and underpier exchange material with the cleaner underlying sediments.

Alternative 2B(12) followed the same general patterns as Alternative 1A(12), and used the same input parameters for bounding. For the reduction in bioavailability parameter[9], the higher reduction percent resulted in a lower predicted SWAC value. Therefore, the higher reduction percent was used for the lowest bound scenario, and the lower reduction percent was used for the highest bound scenario.

A summary of the input variables associated with the lowest and highest bounding scenarios are provided in Table 4.

The lowest and highest bound scenarios represent conditions where all of the input parameters that would influence either a high or low SWAC would occur at the same time; which has a very low probability of occurrence. As shown in Figures 3b and 4b, and discussed earlier, the NSR and Green River chemistry have the greatest input on the predicted SWAC calculations. Therefore, these input parameters will have the greatest impact on the spread between the lowest and highest bounding scenarios. To illustrate the impact of NSR and Green River chemistry on the uncertainty of the SWAC predictions, four additional bounding scenarios were conducted; two scenarios that retained the NSR and Green River chemistry at base case values and varied all other input parameters, and two scenarios and varied only the Green River chemistry:

- Additional Low
- Additional High
- Green Low
- Green High

The inputs for these four additional scenarios are also summarized in Table 4.

The SWAC values predicted using the bounding and base case scenarios are provided in Table 6 and shown graphically in Figure 5a for Alternative 1A(12) and Figure 5b for Alternative 2B(12). The range of predicted SWAC values shown in Figures 5a and 5b for the highest and lowest bounding scenarios suggest that SWAC values for the EW predicted by the box model could vary by up to +125% and -75% at year 10, and by up to +110% and -80% at year 30 due primarily to the significant influence of Green River chemistry and NSR.

[9] This parameter is not applicable to Alternative 1A(12) because in situ treatment is not one of the technologies used.

Looking at the additional high and low bounding scenarios, which hold the Green River chemistry and NSR at base case values while varying all other parameters, the SWAC values predicted by the box model vary by +50% and -40% at year 10 and by up to +20% and -25% at year 30. Considering only the Green River chemistry effects, the SWAC values predicted by the box model vary by +25% and -25% at year 10, and by up to +40% and -40% at year 30.

3 RAO 3 PERFORMANCE OVER TIME (POINT MIXING MODEL EVALUATION)

The box model evaluation described in Section 2 above was used to estimate SWACs for alternatives to assess achievement of RAOs 1, 2, and 4, which are evaluated based on area-average concentrations. RAO 3 however, while evaluated for the site as a whole, is based on individual point locations as opposed to area averages. Therefore, an additional modeling calculation, referred to as the point mixing model evaluation, was conducted to assist in achieving RAO 3. The point mixing model evaluation was conducted on a subset of seven risk-driver COCs for RAO 3. The seven COCs were selected to be representative of the 29 Washington State Sediment Management Standards (SMS) contaminants identified as benthic invertebrate community COCs in the ERA:

1. PCBs
2. Arsenic
3. Mercury
4. High-molecular-weight polycyclic aromatic hydrocarbons (HPAHs)
5. Low-molecular-weight polycyclic aromatic hydrocarbons (LPAHs)
6. Bis(2-ethylhexyl)phthalate (BEHP)
7. 1,4-dichlorobenzene

The point mixing model was only applied where MNR is used as a remedial technology (Alternative 1A(12) only) because all other surface sediment stations will meet RAO 3 preliminary remediation goals (PRGs) following construction, either through active remediation or because they are currently below RAO 3 PRGs. The point mixing model predicts surface sediment concentrations for years 0 through 40 post-construction for the 18 existing surface sediment sampling station locations in proposed MNR areas that exceed the RAO 3 PRGs.

The calculations were conducted for each point location using similar methodology as the box model evaluation described in Section 2; where deposition of incoming solids and vertical mixing assumptions were applied to each point location. Exchange between underpier and open-water areas was not included in these calculations, to provide a conservative estimate of natural recovery in these locations. This assumption tends to bias the predicted sediment concentrations high because the calculations do not account for cleaner sediment from open-water areas accumulating in the underpier locations.

3.1 Input Variables

The variables used as input for the point mixing model are outlined in Chart 4 and discussed in more detail below.

Chart 4
Input Variables for the Point Mixing Model

Input or Variable	Variable or Constant for Analysis	Location of Details
Current representative annual NSR at each MNR point (upstream sources)	Constant over the EW and time.	Section 3.3 and Table 7 herein
Future annual sedimentation rate at MNR point (upstream sources)	Constant over the EW and time.	Section 3.3 and Table 7 herein
Current annual sedimentation from EW laterals	Variable by MNR point (based on PTM output), constant over time.	FS Appendix B, Part 1
Future annual sedimentation from EW laterals	Variable by MNR point (based on PTM output), constant over time.	FS Appendix B, Part 1
Chemistry of surface sediment at year 0	Variable by MNR point based on SRI[1] data.	Table 7 herein
Chemistry of current incoming solids for upstream and EW laterals	Chemistry per point varies, but chemistry used at each point is constant for years 1 to 10.	FS Table 5-3
Chemistry of future incoming solids for upstream and EW laterals	Chemistry per point varies, but chemistry used at each point is constant for years 11 to 40, based on future source control.	FS Table 5-3
Vertical mixing depth assumptions	Variable by point (based on estimated propwash depths, see FS Figure 5-3), constant over time.	Section 3.3 herein

Notes:
1. *Final Supplemental Remedial Investigation Report* (SRI; Windward and Anchor QEA 2014).
EW – East Waterway
FS – Feasibility Study
MNR – monitored natural recovery
NSR – net sedimentation rate
PTM – particle tracking model

The point mixing model was used to predict the surface concentrations for 18 points (15 located in underpier areas and three in under-bridge areas) for the seven risk driver COCs for RAO 3, based on anticipated solids deposition and vertical mixing assumptions. The current surface concentrations for each of the 18 sediment locations were derived from sampling conducted between 2001 and 2009, as shown in Figure 6. These calculations used results from the PTM (FS Appendix B) to establish the deposition from lateral sources at each individual surface point. This is different than the box model evaluation, which assumed that depositing sediments from both upstream and EW lateral sources settled evenly through the EW.

Table 7 lists the MNR points by station name, their locations, the specific deposition rates derived from the PTM results at each MNR point location, and the chemistries used for the calculations. The current surface concentrations were assumed to be the measured concentrations from the EW SRI surface sediment samples collected at each of the 18 locations (Windward and Anchor QEA 2014). The NSR at each point is based on the deposition patterns for the area around the sample location from the PTM (FS Appendix B). As the amount of sediment from the different sources varies by point location, the incoming chemistry concentration is also varied based on the source's chemistry. See Section 3.3 for a calculation of incoming solids concentrations.

The vertical mixing depth assumptions were the same as used in the box model evaluation (FS Figure 5-2). Underpier areas were assumed to be fully mixed by volume in the box model evaluation. Volumetric mixing is not applicable to this evaluation, which focuses on single point locations (as opposed to areas). Therefore, the volumetric mixing of underpier areas used in the box model evaluation had to be changed to an approximate equivalent mixing depth in underpier areas; as was done in the open-water areas for the box model evaluation. Based on vertical mixing assumptions in the EW shown in Figure 5-2, the majority of the underpier areas are adjacent to open-water areas assigned a 2-foot mixing depth. The typical thickness of underpier sediments in the EW is about 2 feet (see FS Section 2.6) based on probing data. Therefore, the mixing depth in underpier areas (15 of the 18 points) was set to 2 feet. Mixing depth in under-bridge areas (3 of the 18 points: EW09-SS-010, EW09-SS-012, and EW-128) was set to 10 cm for bioturbation mixing because there are no vessel operations next to under-bridge areas.

3.2 Calculations

Surface sediment concentrations over time at each of the 18 MNR points were calculated using similar methodology as used for the box model evaluation discussed in Section 2, including vertical bed model for MNR areas (see Figure 1f), vertical mixing assumptions, incoming solids chemistry, and site-wide NSR.

Current surface concentrations and mixing assumptions at each point, solids deposition and chemistry from upstream sources, and solids deposition and chemistry from EW lateral sources were used to predict surface concentrations at each of the 18 MNR points as a function of time post-construction (0 to 40 years) in 5-year intervals. The predicted surface concentrations were compared to PRG (remedial action level [RAL]/sediment quality standards [SQS]) and cleanup screening level (CSL) values for each COC evaluated.

Current surface concentrations at each point are provided in Table 7. Points in underpier areas used a mixing depth of 2 feet, which is the thickness of underpier sediments based on probing data. This is consistent with the box model assumption that underpier sediments are fully mixed by volume over a 5-year period. Points located in under-bridge areas used a mixing depth of 10 cm.

Solids deposition from upstream sources only (i.e., the Green River, LDW bed sediment and LDW lateral sources) were assumed to be constant throughout the EW, and therefore constant at each point location. The value of total annual upstream deposition from all sources was kept constant for each point for current and future conditions and was set to the value used in the recontamination evaluation (grid model evaluation) discussed in FS Section 4 (1.175 cm/yr). A discussion of how this was calculated is provided in Section 4.3, Step 3 in this appendix.

The solids deposition at each point location from EW lateral sources was taken directly from the results of the PTM. The deposition predicted by the PTM for each EW lateral source (see FS Appendix B, Part 1) was extracted from the 50-foot-by-50-foot grid cell where each point is located (see Figure 6). The total deposition from EW lateral sources extracted at each point location was divided into six different source categories (see Figure 2 in FS Appendix B, Part 1) to allow for different chemistry assumptions:

1. Hinds CSO
2. Lander CSO
3. Hanford #2 CSO
4. Nearshore SDs (see Table 1 in FS Appendix B, Part 1: 33 input locations including outfalls for the Port of Seattle, the City of Seattle, and private outfalls)
5. S. Lander St SD
6. Non-nearshore SDs (see Table 1 in FS Appendix B, Part 1: seven input locations including outfalls for S Hinds St SD and U.S. Coast Guard SD)

The chemistry assumptions for EW lateral sources for this evaluation are different than the box model evaluation (Section 2), which assumed a single chemistry assumption for all stormwater and a single chemistry assumption for all CSO discharges, since that evaluation focused on site-wide average calculations. For this evaluation, EW lateral sources were further divided into the six source categories listed above to add additional resolution to the point mixing model calculations. FS Table 5-3 provides chemistry assumptions for each of the seven COCs evaluated as part of this analysis, for the six source categories listed above. The data and development of these chemistry assumptions for EW laterals are described in FS Appendix B, Part 4. FS Table 5-3 also provides chemistry assumptions for these same COCs for upstream sources. Green River chemistry was developed based on methods outlined in the EW FS Appendix B, Part 3, and chemistry for LDW bed and LDW lateral solids was taken from the LDW FS (AECOM 2012).

The total concentration of solids deposited at each point location was calculated as a weighted average on deposited loads to each point from the various input locations. Equation 16 was used to find the input concentration to the EW at each point location.

$$Incoming\ Solids\ Concentration = \frac{\sum_{i=1}^{9} Input_i Solids * Input_i Concentration}{\sum_{i=1}^{9} Input_i Solids} \qquad (16)$$

where:

$Input_i$ Solids	=	solids deposited from each of the three upstream sources and six categories of EW lateral sources discussed above
$Input_i$ Concentration	=	chemistry for each of the COCs based on solids source (Table 11a and 11b)

The surface concentrations were calculated differently for years 0, 5, and 15. Year 10 used the same equation used to calculate year 5. Year 15 represents the first year that future source control scenarios for EW Laterals were assumed to be fully operational and therefore used in the calculations. Years 20 and onward used the same equation for the concentration of year 15.

Year 0 surface concentration was equal to the existing measured surface concentration at each point.

The years 5 and 10 surface concentrations were calculated using Equation 17.

$$C_n = \frac{5T_c * C_{eqc} + (T_{mix} - 5T_c) * C_{n-5}}{T_{mix}} \tag{17}$$

where:

C_n = concentration of surface sediments for year (n)

C_{eqc} = chemistry of incoming sediments (current conditions)

T_c = annual thickness of deposition sediments (current conditions)

T_{mix} = mixing depth

The years 15 and onward surface concentrations were calculated using Equation 18.

$$C_n = \frac{5T_f * C_{eqf} + (T_{mix} - 5T_f) * C_{n-5}}{T_{mix}} \tag{18}$$

where:

C_{eqf} = chemistry of incoming sediments (future conditions)

T_f = annual thickness of deposition sediments (future conditions)

Table 10 provides a summary of estimated concentrations for each MNR point location.

3.3 Sensitivity Evaluation

There was no separate sensitivity evaluation conducted for the point mixing model approach because the box model sensitivity evaluation described in Section 2.4 was considered to be representative of how the surface sediment concentrations for the 18 MNR points could vary for the given input variables. The calculations carried out in the box model are very similar to those of the point mixing model, with two exceptions: 1) the box model encompasses the entire EW Operable Unit as opposed to discrete points within the EW; and 2) exchange between underpier and open-water areas was not included in the point mixing model. For discussion of how the expected variation in calculated surface sediment concentrations at proposed MNR points effects evaluation of RAO 3 compliance within the context of the FS, refer to FS Section 9.

3.4 Results of Calculations

Surface sediment point concentrations and spatial distributions of the point exceedances over time and for the seven key risk driver COCs are provided in Figures 7a and 7b for the 18 MNR points. Figure 7a calls out the points and years that are predicted to exceed the PRG (RAL/SQS), and Figure 7b calls out the points and years that are predicted to exceed the CSL.

FS Table 9-2a outlines how many points are predicted to exceed the CSL and PRG (RAL/SQS) values for the seven COCs over the 40-year period. RAO 3 will be evaluated based on these results in combination with surface and shallow surface sediment concentrations of the approximately 300 additional points that will be remediated using technologies other than MNR or that under current conditions are below RALs. This evaluation is provided in FS Section 9.

4 RECONTAMINATION POTENTIAL EVALUATION (GRID MODEL EVALUATION)

The grid model evaluation was used to identify discrete areas within the EW where recontamination from EW lateral deposition could be a concern post-construction. The spatial distribution of surface concentrations throughout the EW due to deposited solids from upstream and lateral inputs was estimated for years 0 through 40 post-construction. The predicted percentage of EW surface area exceeding RALs at any time over that 40-year time period was used to identify areas where potential recontamination from incoming sediments could occur, inform future source control efforts, and target general areas where post-construction monitoring may be needed. This evaluation, referred to as the grid model evaluation, is different than the box model evaluation because it uses the spatial distribution of EW lateral solids deposition predicted by the PTM as input rather than a cumulative site-wide value. This evaluation was completed from years 0 to 40 post-construction for nine key risk driver COCs: PCBs, cPAHs, dioxins/furans, arsenic, mercury, HPAHs, LPAHs, BEHP, and 1,4-dichlorobenzene (see FS Section 5.4.2 for more detail on selection of COCs for this analysis).

The evaluation of recontamination potential is challenging in the EW due to the influence of anthropogenic activity, such as propwash, which can resuspend recently deposited finer sediments or mix them into the underlying sediments. The effects of propwash on the spatial distribution of EW lateral solids deposition was not taken into account with the PTM because of the difficulty in accurately quantifying the location, mass, and frequency of solids resuspended by vessel activity[10]. Therefore, the recontamination evaluation focused on identifying areas of concern using RALs as metrics without attempting to quantify surface concentrations in the long term with certainty.

Several assumptions were made to simplify the calculations while still meeting the objective of the evaluation, as discussed in Section 4.3. However, there are two primary assumptions that were developed to focus the evaluation on recontamination potential due to incoming solids. The first is that the initial surface concentrations within the EW (at year 0) were

[10] Not accounting for propwash tends to overestimate the predicted concentrations near outfalls, because post-construction propwash will mix and redistribute higher concentration sediments with surrounding lower concentration sediments.

assumed to be zero. This focuses the results of the evaluation on recontamination from incoming sediment sources only and removes the influence of underlying sediment concentrations. The second is that vertical mixing depths were assumed to be constant throughout the EW and thus set to the bioturbation mixing depth assumed for the EW (10 cm). This limits the amount of dilution of incoming sediment sources that could occur due to deeper vertical mixing, which may be sporadic or not occur at any particular location. Ultimately this recontamination evaluation is just an estimate of what might happen in the future, and therefore, monitoring post-construction will be the best method to evaluate recontamination from incoming sediment sources.

4.1 Input Variables

The inputs required for the recontamination potential evaluation are outlined in Chart 5.

Chart 5
Input Variables for the Grid Model

Input or Variable	Variable or Constant for Analysis	Location of Details
Initial surface sediment concentrations (at Time 0 post-construction)	Constant over the EW	Set to 0 for all COCs
Annual upstream NSR	Constant over the EW and over time	FS Section 5.4.3 and Table 5-10
Chemistry assumptions for upstream solids sources	Constant over time	FS Table 5-3
Chemistry assumptions for EW lateral solids sources (current conditions)	Constant for years 1 through 10 post-construction	FS Table 5-3
Chemistry assumptions for EW lateral solids sources (future conditions)	Constant for years 11 through 40 post-construction	FS Table 5-3
Annual deposition rates from EW lateral sources predicted by PTM (current conditions)	Variable over the EW, constant for years 1 through 10 post-construction	FS Appendix B, Part 1 Figures 6 through 8
Annual deposition rates from EW lateral sources predicted by PTM (future conditions)	Variable over the EW, constant for years 11 through 40 post-construction	FS Appendix B, Part 1 Figures 9 through 11

Notes:
COC – contaminant of concern
EW – East Waterway
FS – Feasibility Study
NSR – net sedimentation rate
PTM – particle tracking model

The total annual upstream NSR from all sources (upstream and EW lateral inputs) was set to 1.2 cm/yr based on the evaluation of NSR from geochronological cores in the EW (see FS Section 5.1.2). The portion of the net sedimentation attributed to upstream sources was calculated as the difference between the NSR assumed for the EW from all sources and annual deposition from EW lateral inputs predicted by the PTM (see Step 3 in Section 4.3). Chemistry assumptions for both the upstream solids and lateral inputs for current and future conditions are shown in FS Table 5-3.

4.2 Calculations

The following equations and assumptions were used to complete the recontamination potential evaluation for the EW to identify areas within the EW where recontamination could be a concern post-construction.

Step 1: Assign Surface Concentrations in the East Waterway at Time 0

The surface concentrations throughout the EW at Time 0 (post-construction) for each COC were assumed to be 0. This assumption was made to focus the evaluation on recontamination potential due to incoming solids.

Step 2: Calculate East Waterway Lateral Solids Deposition

The output of the PTM is the initial deposited location of each sediment parcel input into the model. Each parcel of sediment in the PTM represents 0.5 kg of sediment and is assigned an appropriate sediment size or fall velocity based on the particle size distribution in the input solids load. The PTM refers to sediment parcels as particles. Equation 19 was used to develop deposition rates due to EW lateral inputs in equally sized grid cells throughout the EW for the period of the simulation.

$$EW\ Lateral\ Deposition = \frac{\frac{NP * (kilograms\ per\ particle)}{\rho}}{(area\ of\ cell)} \tag{19}$$

where:

NP = number of particles in each 50-square-foot cell (2,500 ft^2 or 232 m^2)

ρ = density of the deposited sediment (estimated to be 1.5 g/cm³ or 1,500 kg/m³)[11]

Based on Equation 19, the deposition of one particle in a cell is represented by Equation 20.

$$EW\ Lateral\ Deposition = \frac{\frac{1[particle]*(0.5\,[\frac{kilogram}{particle}])}{1500[\frac{kilogram}{m^3}]}}{232[m^2]} = 0.0000014\ m \qquad (20)$$

This deposition is based on the simulation period, which was 28 days. Therefore, the deposition over the simulation time of 28 days was extrapolated (multiplied by a factor of 13.04) to provide predictions for annual deposition rates. A single particle in a cell would represent an annual deposition of 0.000019 meter or 0.002 centimeter spread evenly across the cell.

The EW lateral inputs were divided into six categories based on chemistry assumptions (Step 4), as was done for the point mixing evaluation. See Section 3.3 of this appendix for more information.

Step 3: Determine Upstream Solids Deposition

The method used to estimate the contribution of upstream solids sources (for current conditions) to the average NSR is different from what was used in the box model evaluation. Instead of using the entire EW surface area to estimate an average deposition rate in cm/yr from upstream and EW lateral inputs, the smaller surface area where the PTM predicts deposition from EW lateral inputs was used (the shaded areas shown in Figures 7 through 12 in FS Appendix B, Part 1). This results in a slightly larger contribution from EW lateral inputs (in cm/yr over that smaller area) in those locations compared to how it was depicted in the box model evaluation, where deposition from EW lateral inputs were spread evenly throughout the entire EW area. The contribution from upstream sources for current conditions in those locations is calculated as shown in Equation 21, by subtracting the

[11] Based on site-specific SEDflume data in the EW.

contribution from EW lateral sources (all six categories combined) from the assumed representative NSR measured by geochronological cores (1.2 cm/yr[12]).

$$Annual\ Upstream\ Sed\ Rate = Annual\ Sed\ Rate - Annual\ EW\ Lateral\ Sed\ Rate \quad (21)$$

where:

$Sed\ Rate$ = sedimentation rate (or deposition rate)

The specific values for the calculation and a summary of the calculations are outlined in Table 10. The NSR for upstream is estimated to be 1.175 cm/yr for the current base case condition. This upstream deposition is used for both current and future conditions.

Step 4: Assign Concentrations to Upstream and East Waterway Lateral Solids

Different chemistry values are assumed for the six different categories of lateral inputs, and three different chemistry values are included for the upstream portion (i.e., the Green River, LDW bed sediment, and LDW lateral inputs). The chemical concentrations for the EW lateral inputs are discussed in further detail in Part 4 of FS Appendix B, and the upstream chemical concentrations were based on results from the LDW FS (AECOM 2012). Inputs used for the recontamination potential evaluation are outlined in FS Table 5-3 for current and future conditions, respectively.

Step 5: Calculate Lateral input derived Surface Concentrations at 5-year time steps

To calculate the surface concentration, the top 10 cm of the bed is combined including the annual EW lateral deposition, upstream deposition, and in situ sediment. For this analysis all surface concentrations were set to zero at end of construction (year 0).

For each following year, the preceding year is used as the base, with an annual deposition added from upstream and EW lateral inputs. The surface concentration is calculated by mixing the top 10 cm using Equation 22.

[12] This value represents the average of the net sedimentation rate calculated from evaluation of geochronological cores as described in FS Section 5.1.3.

$$Year_n\ Surface\ Concentration = \frac{(Lat_t)*(Lat_C)+(Up_t)*(Up_C)+\left(10\ cm-(Lat_t+Up_t)\right)*Year_{n-1\_C}}{10\ cm} \quad (22)$$

where:

cm	=	centimeters
Lat_t	=	lateral deposition thickness
Lat_C	=	lateral concentration
Up_t	=	upstream deposition thickness
Up_C	=	upstream concentration
$Year_{n-1\_C}$	=	previous year's surface concentration

Current conditions for lateral inputs were used for years 1 through 10, and future conditions were used for years 11 through 30.

4.3 Results

The results of the recontamination evaluation for all nine COCs are shown in FS Figure 9-7, which are used to highlight areas with elevated potential for recontamination based on results for years 0 to 10 post-remediation. The results of this evaluation are discussed in FS Section 9.

4.4 Bounding Evaluation

The predicted range in annual solids deposition due to EW lateral solids (see FS Appendix B, Part 1) and range of potential chemistry for EW lateral solids (see FS Appendix B, Part 5) were used to develop bounding scenarios for the recontamination potential evaluation. Scenarios are outlined in Table 11 and combine higher predicted solids deposition with higher chemistry assumptions, and lower predicted solids deposition with lower chemistry assumptions to provide bounding runs. The purpose of the bounding runs was to determine changes to the spatial area identified as having an elevated potential for recontamination (Section 4.4) based on potential range of EW solids deposition (FS Appendix B, Part 1) and chemistry values (FS Table 5-3). The bounding evaluation was completed for three representative COCs based on the results of the base case runs as follows:

- One COC where surface concentrations are predicted to be below RAL for all years (PCBs)
- One COC where surface concentrations are predicted to be above RAL initially, and then fall below RAL after year 10 (dioxins/furans)
- One COC where surface concentrations are predicted to be above RAL for all years (BEHP)

The results of the bounding evaluation are shown in Figures 8a and 8b for PCBs, Figures 9a and 9b for dioxins/furans, and Figures 10a and 10b for BEHP.

In Figure 8a, the cells that have a concentration for PCB (Scenarios 1 and 2 of Table 11) that exceed the RAL for years 0 through 10 are highlighted. Figure 8b highlights the cells that have a concentration for PCB that exceed the RAL for years 11 to 40. In the case of PCB scenarios, only the higher bounding scenario (higher deposition and higher chemical concentrations) led to exceedances in a few discrete locations close to outfalls.

Figure 9a shows predicted dioxins/furans exceedances for years 0 to 10, and Figure 9b shows predicted exceedances for years 11 to 40 (Scenarios 3 and 4 of Table 11). In the lower bound scenario (lower deposition and lower chemical concentrations) for years 0 to 10, there was only one discrete area in the EW that exceeded the RAL of 25 ng TEQ/kg dw, and there were no exceedances for the future condition years. In the higher bound scenario for dioxins/furans, there are a few more discrete areas close to outfalls that have RALs exceedances for dioxins/furans.

Figure 10a shows predicted BEHP exceedances for years 0 to 10, and Figure 10b shows predicted exceedances for years 11 to 40 (Scenarios 5 and 6 of Table 11). The lower bound scenario for years 0 to 10 shows discrete locations (less than ten) that show exceedances for both current and future conditions years. In the higher bound scenario, the area of exceedance extends beyond the few discrete locations next to outfalls shown in the lower bounding run, but still represents a small fraction of the EW.

The results of the bounding evaluation show the following trends:

- All COCs had less areas of concern for the low bounding runs. PCB had no areas of concern for the low bounding run.
- All COCs had additional areas of concern based on the high bounding run. However, these areas represent a small portion of the EW area and do not extend far from source outfalls.
- Dioxins/furans had a small reduction in areas of concern once proposed future source control actions were accounted for. PCB and BEHP did not have any reduction in predicted areas of concern due to proposed source control actions.

5 ADDITIONAL CONSIDERATIONS

Results from the sediment transport evaluation (STE) completed for the EW and the updated Physical Processes conceptual site model (CSM) developed as part of the EW SRI (Windward and Anchor QEA 2014) and the EW FS are being used as input to the evaluation of site performance over time and recontamination potential within the EW, post-remediation. The effects on predictions of hydrodynamics and sediment transport due to uncertainty in data collection methods, hydrodynamic and PTM inputs, and specific model parameters were investigated as part of the STE and a description of those analyses are provided in the STER (Anchor QEA and Coast & Harbor Engineering 2012).

Specific discussion of uncertainties associated with prediction of site performance over time and recommendation potential based on the chosen values for input variables are discussed in the previous sections of this appendix summarized below:

- Site performance over time, predicted SWAC values (box model evaluation); see Sections 2.4.2 and 2.4.3
- Site performance over time, proposed MNR areas (point mixing model evaluation); see Section 3.4
- Recontamination potential (grid model evaluation); see Section 4.5

This section provides discussion of other considerations that could introduce uncertainty into the evaluation of site performance over time and/or recontamination potential. Much of this information has already been provided in the STER (Anchor QEA and Coast & Harbor Engineering 2012) or EW SRI (Windward and Anchor QEA 2014); however, it is re-summarized here for the reader's benefit. These considerations have been separated into three general categories as described below:

- Considerations related to estimates of input data (i.e., NSR and vertical mixing) taken from the STE and updated Physical Processes CSM are discussed in Section 5.1.
- Considerations associated with calculation methodology developed to estimate SWAC values over time (box model evaluation) and surface concentrations over time in proposed MNR areas (point mixing model evaluation) are discussed in Section 5.2.
- Considerations associated with methodology developed to evaluate recontamination potential due to deposition of EW lateral sediments are discussed in Section 5.3.

5.1 Considerations Associated with Input Data from Sediment Transport Evaluation

This section discusses other considerations that could introduce uncertainties in the evaluations of site performance over time and recontamination potential in the EW FS associated specifically with measurements or calculations of the input data used. The information provided in this section is a summary of more detailed discussions published previously in the STER (Anchor QEA and Coast & Harbor Engineering 2012) and EW SRI (Windward and Anchor QEA 2014).

5.1.1 Representative Net Sedimentation Rate

A representative NSR of 1.2 cm/yr was assumed for the entire EW for the purposes of the FS modeling (see FS Section 5.1.2). This value is the site-wide area average value of net sedimentation calculated from evaluation of NSRs interpreted from geochronological cores for Cs-137 and Pb-210 collected in the EW as part of the STE (see FS Figure 5-1). There is uncertainty in this assumed value of NSR that can be applied for EW as a whole due to variation of estimates of estimated NSRs throughout the EW from the empirical evaluation conducted as part of the STER (0 to 4.2 cm/yr; Anchor QEA and Coast & Harbor Engineering 2012). There is additional uncertainty associated with extrapolating NSRs measured at discrete geochronological core locations to the entire EW area due to influence of vessel operations in the EW on NSRs (e.g., resuspension and re-distribution of EW bed sediments by propwash).

5.1.2 Propwash Impacts to Deposition Patterns

Patterns of solids deposition within the EW from EW Lateral sources based on PTM (see FS Appendix B, Part 1) represent the initial deposition patterns and do not take into account re-suspension or re-distribution of these sediments due to influence of vessel operations in the EW. Deposition patterns shown in Appendix B, Part 1 would likely be more spread out than shown, but would result in lower surface sediment chemical concentrations due to the deposited material being spread out over a larger area. Therefore, the areas identified as having increased potential for recontamination post-construction are approximate. This will be considered when developing the proposed monitoring plan during design.

5.1.3 Upstream Solids Inputs

Uncertainty exists in the chemistry estimates and solids loadings input from upstream sources (Green River, LDW bed sediments, and LDW laterals). This uncertainty will exist well into the future based on the variable nature of these sources. However, a range of concentrations were developed (in Section 5) to evaluate the uncertainty in upstream values. Specifically, the input (e.g., Base Case) values were bracketed by lower- and upper-bound values.

In general, the value representing a mid-range of the various lines of evidence was considered for the input value, and then values representing upper and lower bounds were selected for the high and low sensitivity input values, respectively. One goal of including a range in the input values is to account for uncertainty in all the datasets representing upstream inputs and show how these data ranges affect the long term predictions for the remedial alternatives.

The high end of the range (high chemistry and high solids) is intended to capture variability in the source concentrations, typical seasonal high flows, and the less frequent high flow events (e.g., 100-year flood) that is considered likely to overestimate contaminant concentrations. The low end of the range (low chemistry and low solids) represents a non-conservative set of assumptions that is considered likely to underestimate contaminant concentrations.

The incoming solids from upstream to the EW were based on the outgoing solids estimated from the LDW Sediment Transport Modeling Report (STM; Windward and QEA 2008), which, like all models, has uncertainty. The upstream load from the LDW STM was used to partition the upstream load between the three contributing sources (Green River, LDW bed, and LDW laterals). There is some uncertainty that the distribution of inputs upstream of the EW/WW split matches the distribution entering the EW.

Chemistry assumptions for LDW bed and LDW lateral sediment sources were taken from values provided in the LDW FS (AECOM 2012). LDW bed and lateral sediment inputs were not varied for the sensitivity analysis because the mass of sediment that enters the EW from these sources are small compared to other upstream inputs (i.e., Green River) and do not have a large effect on long-term SWACs for the alternatives. Chemistry assumptions for Green River input (as described in FS Appendix B, Part 3B) considered the same datasets for use in the LDW (AECOM 2012), but selected different concentrations of certain parameters due to a lower percentage of coarse-grained sediment entering the EW from upstream. These datasets are considered reasonable lines of evidence for developing incoming concentrations to the EW from upstream, although each type of data collection tends to bias the results toward lower or higher values (e.g., low percent fines versus high percent fines; single collection events instead of seasonal collection events; potential influence of sources).

5.1.4 East Waterway Lateral Solids Inputs

The uncertainties in the incoming solids input from EW laterals include particle size distributions, stormwater and CSO flows, and total suspended solids concentrations. Appendix F of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012) provides detailed information on how this information was developed for use in the PTM.

There is additional uncertainty associated with the use of shorter-term PTM simulations performed to provide information used to evaluate long-term deposition in the EW from lateral sources. This involved using a representative tidal condition and temporally-constant mean annual average riverine inflow (for the hydrodynamic model used as input to the PTM) and annual average sediment source input rates. This information, while not representative of any particular storm event, provided average initial deposition rates and patterns from EW lateral solids inputs into the EW.

Uncertainties in chemistry assumptions include assignments of the same chemistry values to different outfalls, future concentrations following additional source control actions, as well as chemistry associated with the specific particle sizes that will settle onto EW bed sediments. For example, the same chemistry value was assigned to all nearshore storm drain basins in the point mixing model and grid model evaluations for the reasons listed in FS Appendix B, Part 4 (e.g., consideration of number of samples for a given basin). In addition, the source tracing dataset for SDs included catch basins that are related to a smaller area within the basin and may not be representative of what ultimately is discharged through the outfall. Collectively, these assumptions may lead to over or underestimation of contaminant concentrations for an individual basin.

5.1.5 Vertical Mixing Assumptions

5.1.5.1 Delineation of Vessel Operational Areas

The EW was divided into areas in which vessel operations activities and vessel types were similar as part of the EW STE. These vessel operational areas were used in the FS to calculate scour depths and develop vertical mixing depth assumptions in the EW. Fourteen separate areas and sub-areas were identified. The areas and operations were developed through interviews and personal conversations with individuals that work within the EW including pilots, operations managers, U.S. Coast Guard officials, Port planners, and others (see Section 5.1.2 of the STER; Anchor QEA and Coast & Harbor Engineering 2012). Therefore, uncertainty in the delineation of vessel operational areas is primarily dependent on the reliability of this information for specific areas and changes over time. This uncertainty is taken into account by using conservative operational criteria for the propwash simulations (conducted as part of the STE) based on an understanding of vessel operations. However, there is still some uncertainty in the definitions of specific vessel operation parameters for each scenario (e.g., percent power used for bow thrusters and actual tug operations). Additional uncertainties exist in the location of transitions between operational areas.

5.1.5.2 Prediction of Scour Depths

Scenarios used to estimate scour depths in the EW have been chosen to represent extreme conditions, as defined in Section 5.1.2 of the STER (Anchor QEA and Coast & Harbor Engineering 2012), within each of the defined vessel operational areas in the EW (see Section 5.1.5.1 above). These scenarios are anticipated to drive sediment mobilization in the EW (due to propwash) to a larger extent than a single emergency maneuver or event. The scour depths were predicted by propwash modeling is outlined in FS Appendix B, Part 2.

Uncertainty in estimates of scour depth, as with the delineation of operational areas, are primarily associated with uncertainty in information gathered about vessel operations during the STE. Additional uncertainty is associated with estimates of critical shear stress of surface sediments in the EW. The uncertainties in estimates of critical shear stress, as evaluated from

SEDflume data as part of the STE, include collection effects on sediment properties, experimental error during testing, methodology used to estimate critical shear stress, and spatial variability in erosion properties. While spatial variability in critical shear stress in the EW based on SEDflume data does exist, the representative range in critical shear stress for surface sediments was estimated to be about 0.20 to 0.37 Pa.

Additional uncertainty in prediction of scour depths in the EW can be attributed to the methodology and equations used to complete the calculations (FS Appendix B, Part 2). The equations used in the described methodology have constants that were developed through empirical methods that may not be completely representative of vessel operations and conditions within the EW. Uncertainties in calculation of scour depths were taken into account through use of conservative assumptions, including shallower water depths (operations at mean lower low water) and relatively high power assumptions for vessel operations.

5.1.6 Bed Replacement Values

Post-construction sediment bed replacement values are used as input for modeling for post-construction starting conditions. These values are predictions that represent the initial (or end of construction - Time 0) bed sediment contaminant concentrations following completion of remedial activities involving dredging and placement of RMC, capping, or ENR material. Bed replacement values affect the short term surface concentrations but other variables contribute to the long term predictions of surface concentrations in the EW. Evidence from other sediment sites has shown that contaminant concentrations in the sediment bed after completing a remedial action cannot be assumed to be zero (NRC 2008; EPA 2005), as a result of resettling of contaminated sediments suspended during remedial activities, material being used for RMC following dredging may contain low concentrations of key risk driver COCs, and propwash from large ships in the EW will mix dredge residuals, RMC, and existing sediments around the site. The degree of residual contamination is dependent on the type of remedial activity, specific design elements, construction methods; best management practices (BMPs), engineering controls, contingency measures, and other variables, the effects of which cannot be accurately predicted through modeling.

In the EW, replacement values were developed for 1) remediated areas and 2) interior unremediated areas. FS Appendix B, Part 3A describes the input, low, and high replacement values. This range is intended to capture the uncertainty associated with any of the variables that contribute to the actual post-construction surface sediment concentration.

The most important variables that affect the post-construction surface sediment concentration estimated for the EW are the dredge residuals concentrations and thickness. Thickness of dredge cut, type of dredge equipment, and use of BMPs will affect the dredge residuals thickness. The concentration of sediment being dredged (especially the last pass for dredging areas where multiple passes are required) also varies throughout the EW and will influence dredge residuals concentrations. As described in FS Appendix B, Part 5, variables that affect the dredge residuals thickness, concentration, and distribution include hydrodynamic and operational conditions within the EW during dredging and placement of RMC, including water depth, anticipated duration it would take to place clean material over the entire open-water remediation area (which could require a full construction season due to the extensive size of the anticipated remediation area), and frequency of ongoing vessel traffic in the EW that causes sediment resuspension and sediment bed mixing.

In addition, actual undredged sediment concentrations in remediated and interior unremediated areas following construction affect the post-construction sediment concentration. In areas where limited or no dredge residuals have been deposited and sediment with low concentrations is exposed, the post-construction concentrations may be closer to the low replacement value shown in FS Appendix B, Part 3A. Alternately, where a thicker layer of dredge residuals have deposited, dredge residuals concentrations are higher, or mixing from propwash or placement of RMC spreads contaminated sediment, post-construction concentrations may result in concentrations closer to the high estimate shown in FS Appendix B, Part 3A.

5.2 Considerations Associated with Calculation Methodology for SWAC Values (Box Model Evaluation and Point Mixing Model Evaluation)

In addition to uncertainty in input data, additional uncertainty in predicted SWAC values from the box and point mixing models can be attributed to the methodology developed for those calculations (i.e., vertical mixing assumptions, time frame assumed for mixing to occur, etc.). In order to account for this uncertainty, bounding and sensitivity evaluations were conducted as described in Sections 2.3 and 2.4 of this appendix. Additional considerations that could introduce uncertainty in predictions of SWAC values using the box model evaluation or point mixing model evaluation are discussed in the following sections.

5.2.1 Post-construction (Year 0) Sediment Concentrations

The post-construction (year 0) sediment concentrations estimated for each remedial technology have not taken into account that construction will take place over multiple in-water construction seasons. Instead, the model assumes that all remediation is completed at one time; bed disturbance and deposition that occurs between construction seasons is not taken into account in the estimates of year 0 sediment concentrations.

5.2.2 Vertical Bed Mixing Model and Mixing Depth Assumptions

The vertical bed mixing models (shown in Figures 1a through 1j) are idealized models used to represent the sediment bed post-construction (year 0) for each remedial alternative, as well as sediment deposition and vertical mixing for years following year 0. It is understood that existing bottom sediments, placed sediment, and natural sedimentation within the EW will not resemble even constant layers of sediment as shown in Figures 1a through 1j. This simplification was used to facilitate calculations of long term surface concentrations within the EW.

Vertical mixing assumptions were developed based on calculations of scour depth within the EW, which varied from 0.5 to almost 5 feet depending on location and vessel use (see FS Figure 5-2). However, the range of predicted scour depths was simplified in the evaluation of site performance over time by dividing the EW into areas which were assigned one of four mixing depths: 10 cm (bioturbation), 0.5 feet, 1 foot, and a maximum mixing depth of 2 feet (see Section 2.2.4).

5.2.3 Exchange between Open-water and Underpier Areas

An exchange of sediment between open-water and underpier areas is expected to occur in the EW due to resuspension and distribution of sediments due to impacts from vessel operations, including use of bow thrusters and other propwash scenarios. It is not possible to calculate this exchange rate with any precision due to the variability in vessel operations and underpier sediment characteristics. Therefore, the physical process was simulated in the model through a mass-balance exchange of sediment between open-water and underpier areas.

5.2.4 Timeframe for Complete Mixing in the East Waterway

The timeframe for the EW to completely mix both spatially and vertically to the estimated mixing depths is difficult to predict due to spatial and temporal variability in vessel operations and spatial variability of sediment conditions within the EW. Therefore, the timeframe assumed for complete mixing (i.e., sediments in all open-water areas in the EW are mixed between 10 cm and 2 feet below mudline depending on location) to occur was assumed to be 5 years. Since this timeframe is difficult to predict using available empirical data (due to complexity of vessel operations in the EW), the uncertainty associated with the timeframe of mixing in the EW was parameterized in the sensitivity analysis using two other related variables: vertical mixing depth and percent of the EW area that was fully mixed in the assumed 5-year timeframe.

5.3 Considerations Associated with the Methodology for Recontamination Evaluation (Grid Model Evaluation)

Considerations associated with the methodology used to evaluate recontamination potential that could introduce uncertainty in the evaluation include assumptions for surface concentrations at year 0 post-remediation and vertical mixing assumptions. Year 0 surface sediment concentrations were all set to zero to focus the evaluation on impacts of sediment deposition on recontamination potential. This will result in lower surface concentrations for a short duration following remediation. However, by Year 10 post-remediation, surface sediment within the top 10 cm will consist almost entirely of deposited sediment from upstream and EW lateral sources based on the representative NSR for the EW used in the FS (1.2 cm/yr). This is because vertical mixing due to vessel operations was not considered as part of the recontamination evaluation; and mixing depths in the EW were all set to the bioturbation mixing depth of 10 cm. The deposition patterns predicted by the PTM for EW laterals do not take into account impacts of re-suspension due to vessel operations. Therefore, deposition patterns predicted by the PTM (used as input for the grid model evaluation) would likely be more spread out and would have lower calculated surface sediment chemical concentrations due to the deposited material being spread out over a larger area. Therefore, the areas identified as having increased potential for recontamination post-restoration are approximate. This will be considered when developing the proposed monitoring plan during design.

6 REFERENCES

AECOM, 2012. Feasibility Study, Lower Duwamish Waterway, Seattle, Washington. Final Report. Prepared for Lower Duwamish Waterway Group. October 2012.

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QEA (Quantitative Environmental Analysis), 2008. Lower Duwamish Waterway Sediment Transport Modeling (STM) Report, Final. Prepared for USEPA, Region 10, and the Washington State Department of Ecology. Quantitative Environmental Analysis, Montvale, NJ. October.

Windward and Anchor QEA, 2014. Supplemental Remedial Investigation. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Final. January 2014.

TABLES

Table 1

Summary of Solids Inputs to the East Waterway

Current Conditions

Input	Source	Total Annual Incoming Sediment (kg)[1]	Cumulative Total Annual Incoming Sediment (kg)[2]	Annual Incoming Sediment by Size (kg)[3] A (0.005 mm)	B (0.02 mm)	C (0.13 mm)	D (0.54 mm)	Total Annual Deposited Sediment (kg)[4]	% Total Deposited Sediment[4]
Upstream	Green River	32,159,000 to 53,598,000[5]	32,415,000 to 53,998,000[5]	29,013,000 to 48,355,000	3,145,000 to 5,242,000	199 to 332	29 to 49	15,116,510	99%
	LDW Lateral	178,000 to 296,000[5]		161,000 to 267,000	17,000 to 29,000	1.1 to 1.8	0.1 to 0.3	83,803	0.55%
	LDW Bed	78,000 to 131,000[5]		70,000 to 118,000	7,600 to 12,800	0.5 to 0.8	0.07 to 0.12	36,569	0.24%
EW Laterals	Hinds CSO	326	37,471	137	133	55	0	176	0.00%
	Lander CSO	12,957		5,442	5,312	2,203	0	8,000	0.05%
	Hanford #2 CSO	24,188		10,159	9,917	4,112	0	13,642	0.09%
	Nearshore SD[6]	33,357	75,623	5,137	7,706	8,706	11,809	27,682	0.18%
	S Lander St SD	31,940		4,919	7,378	8,337	11,307	27,089	0.18%
	Non-nearshore SD[7]	10,326		1,590	2,385	2,695	3,655	8,040	0.05%

Future Source Control Conditions (Values are the same as current conditions [grey text] except where noted [bold black text])

Input	Source	Total Annual Incoming Sediment (kg)[1]	Cumulative Total Annual Incoming Sediment (kg)[2]	Annual Incoming Sediment by Size (kg)[3] A (0.005 mm)	B (0.02 mm)	C (0.13 mm)	D (0.54 mm)	Total Annual Deposited Sediment (kg)[4]	% Total Deposited Sediment[4]
Upstream	Green River	32,159,000 to 53,598,000[5]	32,415,000 to 53,998,000[5]	29,013,000 to 48,355,000	3,145,000 to 5,242,000	199 to 332	29 to 49	15,116,510	99%
	LDW Lateral	178,000 to 296,000[5]		161,000 to 267,000	17,000 to 29,000	1.1 to 1.8	0.1 to 0.3	83,803	0.55%
	LDW Bed	78,000 to 131,000[5]		70,000 to 118,000	7,600 to 12,800	0.5 to 0.8	0.07 to 0.12	36,569	0.24%
EW Laterals	Hinds CSO	**207**	**16,744**	**87**	**85**	**35**	**0**	**111**	0.00%
	Lander CSO	**195**		**82**	**80**	**33**	**0**	**124**	0.00%
	Hanford #2 CSO	**16,342**		**16,154**	**133**	**55**	**0**	**2,919**	0.02%
	Nearshore SD[6]	**15,594**	**57,860**	**4,115**	**3,819**	**3,251**	**4,409**	**11,206**	0.07%
	S Lander St SD	31,940		4,919	7,378	8,337	11,307	27,089	0.18%
	Non-nearshore SD[7]	10,326		1,590	2,385	2,695	3,655	7,987	0.05%

Notes:
1. Categories of solids sources used for recontamination potential evaluation and Point Mixing Model.
2. Categories of solids sources used for evaluation of site performance over time (SWACs).
3. Upstream annual incoming sediment by size was based on suspended sediment size classes predicted to leave the model domain boundary upstream of the EW and WW split, and averaged over 30 years predicted by the LDW Sediment Transport Model (AECOM 2012).
4. Deposition values based on Base Case PTM Model runs for EW Laterals (see Appendix B, Part 1 of the FS) and average net sedimentation rate for the EW from geochronology cores (see Section 5.1.2 of the FS).
5. Range in values based on range in the estimated split in flow between the EW and WW, 50% to 30% to EW from LDW.
6. Nearshore SDs include SW Florida St SD (B-21), B-25, all Port SDs, and all private SDs along waterfront (A-6, B-40, B-41, B-42, B-43).
7. Non-nearshore SDs include S Hinds St SD, SW Spokane St EOF/SD (B-5), SW Spokane St SD (B-4), S Spokane St SD (B-36), and all bridges (BR-2, BR-4, BR-34, BR-39).
CSO – Combined Sewer Overflow; EW – East Waterway; FS – Feasibility Study; kg – kilogram; LDW – Lower Duwamish Waterway; mm – millimeter; PTM – particle tracking model; SD – Storm Drain; SWAC – spatially-weighted average concentration; WW – West Waterway

Table 2

Alternative-specific Post-construction Concentrations by Technology Application Area

	Total PCBs (µg/kg considering bioavailability)[5]															
	Alternative															
Technology[1]	**1A(12)**	**1B(12)**	**1C+(12)**	**2A(12)**	**2B(12)**	**2C(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**3D(12)**	**3E(7.5)**	**3E(5.0)**	**2C+(7.5)**	**2C+(5.0)**	**3C+(7.5)**	**3D(5.0)**
Open-water																
Removal[2]	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Removal to the Extent Practicable and Backfill[2]	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Removal and Backfill to Existing Contours[3]	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Partial Removal and Cap	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Partial Removal and ENR-nav[4]	35	35	35													
ENR-sill[2]	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
ENR-nav[4]	8	8	8													
MNR	1268			1268												
Interior Unremediated Island[2]	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Exterior Unremediated Island	54	54	54	54	54	54	54	54	54	54	27	20	27	20	27	20
Underpier																
Hydraulic Dredging Followed by In situ Treatment			411				411		411		173	165	411	411	411	0
Hydraulic Dredging						1,371				596						550
In situ Treatment		179	135		179	135	135	179	135				130	124	130	
MNR	596			596												
No Action	81	81	81	81	81	81	81	81	81	81	40	23	40	23	40	23

	Total cPAHs TEQ (µg/kg considering bioavailability)[5]															
	Alternative															
Technology	**1A(12)**	**1B(12)**	**1C+(12)**	**2A(12)**	**2B(12)**	**2C(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**3D(12)**	**3E(7.5)**	**3E(5.0)**	**2C+(7.5)**	**2C+(5.0)**	**3C+(7.5)**	**3D(5.0)**
Open-water																
Removal[2]	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
Removal to the Extent Practicable and Backfill[2]	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
Removal and Backfill to Existing Contours[3]	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
Partial Removal and Cap	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Partial Removal and ENR-nav[4]	28	28	28													
ENR-sill[2]	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
ENR-nav[4]	13	13	13													
MNR	582			582												
Interior Unremediated Island[2]	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Exterior Unremediated Island	164	164	164	164	164	164	164	164	164	164	170	186	170	186	170	186
Underpier																
Hydraulic Dredging Followed by In situ Treatment			423				423		423		196	187	423	423	423	
Hydraulic Dredging						1,409				596						622
In situ Treatment		179	132		179	132	132	179	132				155	147	155	
MNR	596			596												
No Action	540	540	540	540	540	540	540	540	540	540	106	121	106	121	106	121

Table 2

Alternative-specific Post-construction Concentrations by Technology Application Area

Technology[1]	Total Dioxins/Furans TEQ (ng/kg considering bioavailability)[5]															
	Alternative															
	1A(12)	1B(12)	1C+(12)	2A(12)	2B(12)	2C(12)	2C+(12)	3B(12)	3C+(12)	3D(12)	3E(7.5)	3E(5.0)	2C+(7.5)	2C+(5.0)	3C+(7.5)	3D(5.0)
Open-water																
Removal[2]	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Removal to the Extent Practicable and Backfill[2]	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Removal and Backfill to Existing Contours[3]	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Partial Removal and Cap	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Partial Removal and ENR-nav[4]	2.8	2.8	2.8													
ENR-sill[2]	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
ENR-nav[4]	2.2	2.2	2.2													
MNR	17			17												
Interior Unremediated Island[2]	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Exterior Unremediated Island	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.9	8.7	7.9	8.7	7.9	8.7
Underpier																
Hydraulic Dredging Followed by In situ Treatment			4.8				4.8		4.8		4.9	4.9	4.8	4.8	4.8	
Hydraulic Dredging						16				17						16
In situ Treatment		5.0	5.0		5.0	5.0	5.0	5.0	5.0				5.0	4.9	5.0	
MNR	17			17												
No Action	12	12	12	12	12	12	12	12	12	12	12	10	12	10	12	10

Technology[1]	Arsenic (mg/kg)[5]															
	Alternative															
	1A(12)	1B(12)	1C+(12)	2A(12)	2B(12)	2C(12)	2C+(12)	3B(12)	3C+(12)	3D(12)	3E(7.5)	3E(5.0)	2C+(7.5)	2C+(5.0)	3C+(7.5)	3D(5.0)
Open-water																
Removal[2]	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Removal to the Extent Practicable and Backfill[2]	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Removal and Backfill to Existing Contours[3]	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Partial Removal and Cap	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Partial Removal and ENR-nav[4]	4.2	4.2	4.2													
ENR-sill[2]	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
ENR-nav[4]	4.0	4.0	4.0													
MNR	14.8			14.8												
Interior Unremediated Island[2]	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Exterior Unremediated Island	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.3	5.0	5.3	5.0	5.3
Underpier																
Hydraulic Dredging Followed by In situ Treatment			13				13		13		8.4	8.2	13	13	13	
Hydraulic Dredging						20				12						11
In situ Treatment		11	9.5		11	9.5	9.5	11	9.5				10	9.3	10	
MNR	12			12												
No Action	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	4.6	4.5	4.6	4.5	4.6	4.5

Table 2

Alternative-specific Post-construction Concentrations by Technology Application Area

Notes:

1. Residuals thickness varies by alternative; see FS Appendix L and FS Section 8 for this information.
2. Includes 9 inches of sand cover in ENR sill areas in calculations.
3. Includes 4 feet of sand cover in calculations.
4. Includes 1.5 feet of sand cover in ENR-nav areas in calculations.
5. Post-construction concentrations are calculated in the top 10 centimeters of bed sediments.

µg/kg – microgram per kilogram
cPAH – carcinogenic polycyclic aromatic hydrocarbon
ENR – enhanced natural recovery
mg – milligram
MNR – monitored natural recovery
ng – nanogram
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

Table 3

Sub-area Input Values by Remedial Alternative for SWAC Calculations (Box Model Evaluation)

(Total Area of EW for all Remedial Alternatives is 157.4 acres)

Technology[1]	Areas (acres)															
	Alternative															
	1A(12)	1B(12)	1C+(12)	2A(12)	2B(12)	2C(12)	2C+(12)	3B(12)	3C+(12)	3D(12)	3E(7.5)	3E(5.0)	2C+(7.5)	2C+(5.0)	3C+(7.5)	3D(5.0)
Open-water																
Removal[2]	73.2	73.2	73.2	87.9	87.9	87.9	87.9	92.3	92.3	92.3	102.1	109.6	97.7	105.2	102.2	109.6
Removal to the Extent Practicable and Backfill[2]	3.3	3.3	3.3	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Removal and Backfill to Existing Contours[3]	0.7	0.7	0.7	0.7	0.7	0.7	0.7	3.5	3.5	3.5	3.8	3.8	0.8	0.8	3.8	3.8
Partial Removal and Cap	12.8	12.8	12.8	12.8	12.8	12.8	12.8	7.3	7.3	7.3	7.3	7.3	12.8	12.8	7.3	7.3
Partial Removal and ENR-nav[4]	7.4	7.4	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENR-sill[2]	2.4	2.9	2.9	2.4	2.9	2.9	2.9	1.2	1.2	1.2	1.3	1.3	3.2	3.2	1.3	1.3
ENR-nav[4]	8.7	8.7	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MNR	0.5	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
No Action-Interior Unremediated Island[2]	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	15.1	9.2	15.1	9.2	15.1	9.2
No Action-Exterior Unremediated Island	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	8.5	6.9	8.5	6.9	8.5	6.9
Underpier																
Hydraulic Dredging Followed by In situ Treatment	0.0	0.0	1.9	0.0	0.0	0.0	1.9	0.0	1.9	0.0	12.7	13.4	1.9	1.9	1.9	0.0
Hydraulic Dredging	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	12.1	0.0	0.0	0.0	0.0	0.0	13.4
In situ Treatment	0.0	12.1	10.1	0.0	12.1	10.1	10.1	12.1	10.1	0.0	0.0	0.0	10.7	11.5	10.7	0.0
MNR	12.1	0.0	0.0	12.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
No Action-Underpier Unremediated	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.8	1.1	1.9	1.1	1.8	1.1

Notes:
1. Residuals thickness varies by alternative; see FS Appendix L and FS Section 8 for this information.
2. Includes 9 inches of sand cover in ENR-sill areas in calculations.
3. Includes 4 feet of sand cover in calculations.
4. Includes 1.5 feet of sand cover in ENR-nav areas in calculations.
ENR – enhanced natural recovery
EW – East Waterway
MNR – monitored natural recovery
SWAC – spatially-weighted average concentration

Table 4

Sensitivity and Bounding Scenarios for SWAC Calculations (Box Model Evaluation)

Sensitivity Analysis-Review Influence of Each Parameter (Alternatives 1A(12) and 2B(12))

Scenario	Scenario Name	1: Net Sedimentation Rate	2: Residuals Thickness[2]	3: Residuals Concentration	4: Mixing Depth	5: Area Mixed	6: Underpier Exchange	7: Lateral Concentrations[3]	8: Green River Concentrations[3]	9: Bioavailability[4]
1[1]	Base Case	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
2	1: Net Sedimentation Rate-Low	0.5 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
3	1: Net Sedimentation Rate-High	1.8 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
4	1a: Variable NSR	0 cm/0.5 cm/1.6 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
5	2: Residuals Thickness-Low	1.2 cm	3.1 cm; 0.6 cm	640 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
6	2: Residuals Thickness-High	1.2 cm	7.2 cm; 1.4 cm	640 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
7	3: Residuals Concentration-Low	1.2 cm	5.1 cm; 1.0 cm	470 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
8	3: Residuals Concentration-High	1.2 cm	5.1 cm; 1.0 cm	980 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
9	4: Mixing Depth-Low	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	1 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
10	4: Mixing Depth-High	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	3 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
11	5: Area Mixed-Low	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	30%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
12	5: Area Mixed-High	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	90%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
13	6: Underpier Exchange-Low	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	5%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
14	6: Underpier Exchange-High	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	50%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
15	7: Lateral Concentrations-Low	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	25%	45.36 µg/kg; 44.44 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
16	7: Lateral Concentrations-High	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	25%	48.54 µg/kg; 45.52 µg/kg	45.99 µg/kg; 44.72 µg/kg	70%
17	8: Green Concentrations-Low	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	9.58 µg/kg; 8.44 µg/kg	70%
18	8: Green Concentrations-High	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	83.38 µg/kg; 82.31 µg/kg	70%
19	9: Bioavailability-Low	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	50%
20	9: Bioavailability-High	1.2 cm	5.1 cm; 1.0 cm	640 µg/kg	2 feet	50%	25%	45.99 µg/kg; 44.72 µg/kg	45.99 µg/kg; 44.72 µg/kg	90%

Notes:
1. Scenario 1 used as base case for conducting all evaluations (box model, point-by-point mixing model, and grid model).
2. See Appendix B, Part 3A.
3. See Appendix B, Part 4.
4. Underpier bioavailability for underpier areas. Only valid for Alternative 2B(12); Alternative 1A(12) stays constant.
Shaded boxes indicate that the parameter changed compared to the Sensitivity Analysis, Scenario 1.
µg/kg – microgram per kilogram; cm – centimeters; NSR – net sedimentation rate; SWAC – spatially-weighted average concentration

Table 4

Sensitivity and Bounding Scenarios for SWAC Calculations (Box Model Evaluation)

Bounding Scenarios (Alternatives 1A(12) and 2B(12))

Scenario	1: Net Sedimentation Rate	2: Residuals Thickness	3: Residuals Concentration	4: Mixing Depth	5: Area Mixed	6: Underpier Exchange	7: Lateral Concentrations	8: Green River Concentrations	9: Bioavailability[1]
Lowest Bound	High	Low	Low	High	Low	Low	Low	Low	High
Highest Bound	Low	High	High	Low	High	High	High	High	Low
Additional Low	Base	Low	Low	High	Low	Low	Low	Base[2]	High
Additional High	Base	High	High	Low	High	High	High	Base[2]	Low
Green River Low	Base	Base	Base	Base	Base	Base	Base	Low	Base
Green River High	Base	Base	Base	Base	Base	Base	Base	High	Base

Notes:
1. Bioavailability is only applied to sensitivity and bounding runs for Alternative 2B(12); Alternative 1A(12) stays constant.
2. NSR and Green River concentrations left as base case to illustrate the impact these parameters have on the SWAC predictions (see Section 2.3.3).

Table 5

Site-wide Total PCB SWAC (µg/kg dw) Results for Box Model Sensitivity Scenarios[1]

Alternative 1A(12)		Years Post-construction								
Scenario	**Scenario Name**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
1	Base Case	76	131	126	114	103	95	87	82	77
2	1: Net Sedimentation Rate-Low	76	123	143	142	135	127	119	112	106
3	1: Net Sedimentation Rate-High	76	125	111	97	88	81	75	71	67
4	1a: Variable NSR	76	127	122	113	104	97	91	86	82
5	2: Residuals Thickness-Low	76	127	122	110	100	91	84	79	74
6	2: Residuals Thickness-High	76	136	130	118	107	98	91	85	80
7	3: Residuals Concentration-Low	76	128	123	111	101	92	85	80	75
8	3: Residuals Concentration-High	76	138	132	120	109	100	92	86	81
9	4: Mixing Depth-Low	76	131	127	116	105	95	88	81	76
10	4: Mixing Depth-High	76	130	124	112	101	93	86	80	76
11	5: Area Mixed-Low	76	137	132	118	105	95	87	81	76
12	5: Area Mixed-High	76	119	114	107	100	94	89	84	80
13	6: Underpier Exchange-Low	76	98	97	93	89	86	83	80	77
14	6: Underpier Exchange-High	76	173	143	117	101	90	82	77	73
15	7: Lateral Concentrations-Low	76	131	126	114	103	94	87	82	77
16	7: Lateral Concentrations-High	76	132	127	115	104	95	88	83	78
17	8: Green Concentrations-Low	76	118	108	94	81	70	62	55	50
18	8: Green Concentrations-High	76	144	144	136	127	119	114	109	106

Alternative 2B(12)		Years Post-construction								
Scenario	**Scenario Name**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
1	Base Case	42	72	71	68	65	63	60	59	57
2	1: Net Sedimentation Rate-Low	42	67	74	75	74	72	70	68	67
3	1: Net Sedimentation Rate-High	42	71	68	64	61	58	56	55	53
4	1a: Variable NSR	42	69	69	66	63	61	59	58	56
5	2: Residuals Thickness-Low	42	67	67	64	61	59	57	55	54
6	2: Residuals Thickness-High	42	77	76	73	70	67	64	62	60
7	3: Residuals Concentration-Low	42	68	68	65	62	60	58	56	55
8	3: Residuals Concentration-High	42	79	78	75	71	68	66	64	62
9	4: Mixing Depth-Low	42	70	70	67	64	61	58	56	55
10	4: Mixing Depth-High	42	67	67	64	61	59	57	56	54
11	5: Area Mixed-Low	42	71	71	68	65	62	59	58	56
12	5: Area Mixed-High	42	72	71	69	67	64	62	61	59
13	6: Underpier Exchange-Low	42	62	63	62	60	59	58	57	56
14	6: Underpier Exchange-High	42	84	77	70	66	63	60	58	57
15	7: Lateral Concentrations-Low	42	71	71	68	65	62	60	58	57
16	7: Lateral Concentrations-High	42	72	73	69	66	63	61	59	58
17	8: Green Concentrations-Low	42	59	54	48	43	39	35	32	30
18	8: Green Concentrations-High	42	84	89	89	88	87	86	86	85
19	9: Bioavailability-Low	51	90	89	83	78	73	69	66	64
20	9: Bioavailability-High	32	53	54	54	53	52	52	51	50

Notes:
1. All sensitivity runs were conducted using total PCBs, sensitivity scenarios are listed in Table 4.
µg/kg – microgram per kilogram
dw – dry weight
NSR – net sedimentation rate
PCB – polychlorinated biphenyl
SWAC – spatially-weighted average concentration

Table 6
Site-wide Total PCB SWAC (µg/kg dw) Results for Box Model Bounding Scenarios[1]

Alternative 1A(12)	Years Post-construction								
	0	5	10	15	20	25	30	35	40
Base Case	76	131	126	114	103	95	87	82	77
Lowest Bound	76	68	60	54	49	44	41	38	36
Highest Bound	76	196	212	202	192	183	175	168	161
Reasonable Low	76	94	93	90	86	83	80	77	75
Reasonable High	76	162	144	126	111	99	90	83	76
Green Low	76	118	108	94	81	70	62	55	50
Green High	76	144	144	136	127	119	114	109	106

Alternative 2B(12)	Years Post-construction								
	0	5	10	15	20	25	30	35	40
Base Case	42	72	71	68	65	63	60	59	57
Lowest Bound	32	21	19	17	16	15	14	14	13
Highest Bound	51	154	160	149	137	127	118	109	101
Reasonable Low	32	43	45	45	45	45	45	45	45
Reasonable High	51	116	105	95	86	79	73	69	65
Green Low	42	59	54	48	43	39	35	32	30
Green High	42	84	89	89	88	87	86	86	85

Note:
1. All bounding runs were conducted using total PCBs, bounding scenarios are listed in Table 4.
µg/kg – microgram per kilogram
dw – dry weight
PCB – polychlorinated biphenyl
SWAC – spatially-weighted average concentration

Table 7

Point Mixing Model Solids Inputs and Chemistry Assumptions for Calculations

Point	Location[1]		PTM-derived Annual Deposition		Arsenic (mg/kg dw)			Mercury (mg/kg dw)			Total HPAHs (µg/kg dw)			Total LPAHs (µg/kg dw)		
	X Latitude	Y Longitude	Current (cm)	Future[2] (cm)	Current Surface	Current Incoming	Future Incoming	Current Surface	Current Incoming	Future Incoming	Current Surface	Current Incoming	Future Incoming	Current Surface	Current Incoming	Future Incoming
EW09-SS-010	1267383	212101	**1.356**	**1.347**	8.4	9.2	9.2	0.11	0.11	0.11	3040	2343	1940	370	354	300
EW09-SS-012	1267207	212224	**1.199**	**1.199**	6.0	9.0	9.0	0.02	0.10	0.10	2680	1338	1338	360	138	138
EW09-SS-027	1267850	213108	**1.212**	**1.204**	12.1	9.1	9.1	0.40	0.10	0.10	3270	1383	1357	500	147	142
EW09-SS-038	1267846	214050	**1.197**	**1.197**	9.1	9.0	9.0	0.46	0.10	0.10	4240	1331	1331	340	137	137
EW09-SS-100	1267016	214210	**1.210**	**1.199**	6.8	9.1	9.0	0.29	0.10	0.10	2220	1376	1338	350	146	138
EW09-SS-101	1267840	214257	**1.197**	**1.197**	7.5	9.0	9.0	0.47	0.10	0.10	3180	1331	1331	630	137	137
EW09-SS-110	1268243	215019	**1.197**	**1.197**	9.2	9.0	9.0	0.48	0.10	0.10	2120	1331	1331	310	137	137
EW09-SS-114	1267035	215406	**1.197**	**1.197**	22.7	9.0	9.0	0.32	0.10	0.10	1700	1331	1331	250	137	137
EW09-SS-126	1267067	217295	**1.208**	**1.201**	6.4	9.1	9.1	0.17	0.10	0.10	1080	1370	1344	82	145	139
EW09-SS-211	1267130	218822	**1.197**	**1.197**	3.6	9.0	9.0	0.17	0.10	0.10	1940	1331	1331	280	137	137
EW09-SS-219	1267959	219386	**1.197**	**1.197**	3.1	9.0	9.0	0.16	0.10	0.10	1370	1331	1331	400	137	137
EW-109	1267155	218459	**1.197**	**1.197**	9.0	9.0	9.0	0.16	0.10	0.10	6200	1331	1331	1230	137	137
EW-128	1267088	212098	**1.201**	**1.204**	20.0	9.1	9.1	0.31	0.10	0.10	6100	1344	1363	940	139	145
EW-132	1267138	218690	**1.197**	**1.197**	8.0	9.0	9.0	0.19	0.10	0.10	2970	1331	1331	400	137	137
EW-135	1267878	215761	**1.223**	**1.208**	12.0	9.0	9.0	0.47	0.10	0.10	6500	1547	1399	1180	179	150
EW-136	1268185	215025	**1.212**	**1.201**	10.0	9.0	9.0	0.49	0.10	0.10	7600	1431	1354	1700	156	141
EW-138	1267049	213522	**1.197**	**1.197**	10.0	9.0	9.0	0.50	0.10	0.10	6500	1331	1331	750	137	137
LSO-01	1267897.4	215773.5	**1.223**	**1.208**	7.3	9.0	9.0	0.27	0.10	0.10	3910	1547	1399	930	179	150

Table 7
Point Mixing Model Solids Inputs and Chemistry Assumptions for Calculations

Point[1]	Yearly Deposition Current (cm)	Yearly Deposition Future[2] (cm)	BEHP (µg/kg dw) Current Surface	BEHP (µg/kg dw) Current Incoming	BEHP (µg/kg dw) Future Incoming	1,4-DCB (µg/kg dw) Current Surface	1,4-DCB (µg/kg dw) Current Incoming	1,4-DCB (µg/kg dw) Future Incoming	Total PCBs (µg/kg dw) Current Surface	Total PCBs (µg/kg dw) Current Incoming	Total PCBs (µg/kg dw) Future Incoming
EW09-SS-010	**1.356**	**1.347**	520	2357	1700	10.0	17.7	17.0	1130	73.0	61.6
EW09-SS-012	**1.199**	**1.199**	36	172	172	5.8	1.7	1.7	78	44.5	44.5
EW09-SS-027	**1.212**	**1.204**	310	260	210	6.0	2.5	2.0	160	45.7	45.0
EW09-SS-038	**1.197**	**1.197**	340	159	159	460.0	1.6	1.6	1600	44.3	44.3
EW09-SS-100	**1.210**	**1.199**	320	248	172	24.0	2.4	1.7	160	45.6	44.5
EW09-SS-101	**1.197**	**1.197**	1000	159	159	4200.0	1.6	1.6	310	44.3	44.3
EW09-SS-110	**1.197**	**1.197**	180	159	159	17.0	1.6	1.6	140	44.3	44.3
EW09-SS-114	**1.197**	**1.197**	230	159	159	10.0	1.6	1.6	220	44.3	44.3
EW09-SS-126	**1.208**	**1.201**	120	235	185	28.0	2.3	1.8	880	45.4	44.7
EW09-SS-211	**1.197**	**1.197**	830	159	159	10.0	1.6	1.6	180	44.3	44.3
EW09-SS-219	**1.197**	**1.197**	56	159	159	6.1	1.6	1.6	20	44.3	44.3
EW-109	**1.197**	**1.197**	220	159	159	31.0	1.6	1.6	1900	44.3	44.3
EW-128	**1.201**	**1.204**	770	185	237	2.0	1.8	2.3	2400	44.7	45.2
EW-132	**1.197**	**1.197**	300	159	159	1.4	1.6	1.6	330	44.3	44.3
EW-135	**1.223**	**1.208**	1400	363	270	2.0	4.9	2.6	740	45.4	45.0
EW-136	**1.212**	**1.201**	500	255	196	1.9	3.9	1.9	370	44.7	44.5
EW-138	**1.197**	**1.197**	760	159	159	1.8	1.6	1.6	590	44.3	44.3
LSO-01	**1.223**	**1.208**	37000	363	270	20.0	4.9	2.6	340	45.4	45.0

Notes:
1. Locations of points are shown on Figure 5.
2. Future deposition is based on expected future source control conditions for EW Laterals.
µg/kg – microgram per kilogram
BEHP – bis(2-ethylhexyl) phthalate
cm – centimeters
DCB – dichlorobenzene
dw – dry weight
EW – East Waterway
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligram per kilogram
PCB – polychlorinated biphenyl
PTM – particle tracking model

Table 8

Concentrations at Point Locations - Years 0 to 40 Post-construction

PCB (mg/kg OC)[1]				Years Post-construction								
	Mixing Depth	1-year Deposition (cm)		Current Conditions			Future Conditions					
Point	(cm)	Current	Future[2]	0	5	10	15	20	25	30	35	40
EW09-SS-010	10	**1.356**	**1.347**	70.6	25.8	11.4	6.3	4.7	4.1	3.9	3.9	3.9
EW09-SS-012	10	**1.199**	**1.199**	4.9	3.6	3.1	2.9	2.8	2.8	2.8	2.8	2.8
EW09-SS-027	60.96	**1.212**	**1.204**	10.0	9.3	8.7	8.1	7.6	7.1	6.7	6.3	5.9
EW09-SS-038	60.96	**1.197**	**1.197**	100.0	90.5	81.8	74.1	67.1	60.8	55.1	49.9	45.3
EW09-SS-100	60.96	**1.210**	**1.199**	10.0	9.3	8.7	8.1	7.6	7.1	6.7	6.3	5.9
EW09-SS-101	60.96	**1.197**	**1.197**	19.4	17.7	16.3	14.9	13.8	12.7	11.7	10.8	10.0
EW09-SS-110	60.96	**1.197**	**1.197**	8.8	8.2	7.6	7.2	6.7	6.3	6.0	5.7	5.4
EW09-SS-114	60.96	**1.197**	**1.197**	13.8	12.7	11.7	10.8	10.0	9.3	8.7	8.1	7.6
EW09-SS-126	60.96	**1.208**	**1.201**	55.0	49.8	45.2	41.0	37.2	33.8	30.8	28.0	25.5
EW09-SS-211	60.96	**1.197**	**1.197**	11.3	10.4	9.7	9.0	8.4	7.8	7.3	6.9	6.5
EW09-SS-219	60.96	**1.197**	**1.197**	1.3	1.4	1.5	1.7	1.8	1.9	2.0	2.0	2.1
EW-109	60.96	**1.197**	**1.197**	118.8	107.4	97.1	87.8	79.5	72.0	65.2	59.0	53.5
EW-128	10	**1.201**	**1.204**	150.0	61.6	26.3	12.2	6.5	4.3	3.4	3.1	2.9
EW-132	60.96	**1.197**	**1.197**	20.6	18.9	17.3	15.9	14.6	13.4	12.4	11.4	10.6
EW-135	60.96	**1.223**	**1.208**	46.3	41.9	38.0	34.5	31.4	28.5	26.0	23.7	21.6
EW-136	60.96	**1.212**	**1.201**	23.1	21.1	19.3	17.7	16.2	14.9	13.7	12.6	11.6
EW-138	60.96	**1.197**	**1.197**	36.9	33.5	30.5	27.8	25.3	23.1	21.1	19.3	17.7
LSO-01	60.96	**1.223**	**1.208**	21.3	19.4	17.7	16.3	14.9	13.7	12.6	11.7	10.8

Mercury (mg/kg)				Years Post-construction								
	Mixing Depth	1-year Deposition (cm)		Current Conditions			Future Conditions					
Point	(cm)	Current	Future[1]	0	5	10	15	20	25	30	35	40
EW09-SS-010	10	**1.356**	**1.347**	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
EW09-SS-012	10	**1.199**	**1.199**	0.02	0.07	0.09	0.10	0.10	0.10	0.10	0.10	0.10
EW09-SS-027	60.96	**1.212**	**1.204**	0.4	0.37	0.34	0.32	0.30	0.28	0.26	0.25	0.23
EW09-SS-038	60.96	**1.197**	**1.197**	0.46	0.42	0.39	0.36	0.34	0.32	0.29	0.28	0.26
EW09-SS-100	60.96	**1.210**	**1.199**	0.29	0.27	0.25	0.24	0.23	0.21	0.20	0.19	0.18
EW09-SS-101	60.96	**1.197**	**1.197**	0.47	0.43	0.40	0.37	0.35	0.32	0.30	0.28	0.26
EW09-SS-110	60.96	**1.197**	**1.197**	0.48	0.44	0.41	0.38	0.35	0.33	0.31	0.29	0.27
EW09-SS-114	60.96	**1.197**	**1.197**	0.32	0.30	0.28	0.26	0.25	0.23	0.22	0.21	0.20
EW09-SS-126	60.96	**1.208**	**1.201**	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13
EW09-SS-211	60.96	**1.197**	**1.197**	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13
EW09-SS-219	60.96	**1.197**	**1.197**	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13
EW-109	60.96	**1.197**	**1.197**	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13
EW-128	10	**1.201**	**1.204**	0.31	0.19	0.14	0.12	0.11	0.10	0.10	0.10	0.10
EW-132	60.96	**1.197**	**1.197**	0.19	0.18	0.17	0.17	0.16	0.15	0.15	0.14	0.14
EW-135	60.96	**1.223**	**1.208**	0.47	0.43	0.40	0.37	0.34	0.32	0.30	0.28	0.26
EW-136	60.96	**1.212**	**1.201**	0.49	0.45	0.42	0.39	0.36	0.33	0.31	0.29	0.27
EW-138	60.96	**1.197**	**1.197**	0.5	0.46	0.43	0.39	0.37	0.34	0.32	0.30	0.28
LSO-01	60.96	**1.223**	**1.208**	0.274	0.26	0.24	0.23	0.22	0.20	0.19	0.19	0.18

Table 8

Concentrations at Point Locations - Years 0 to 40 Post-construction

BEHP (mg/kg OC)[1]				Years Post-construction								
	Mixing Depth	1-year Deposition (cm)		Current Conditions			Future Conditions					
Point	(cm)	Current	Future[1]	0	5	10	15	20	25	30	35	40
EW09-SS-010	10	**1.356**	**1.347**	32.5	110.4	135.4	115.8	109.3	107.2	106.6	106.3	106.3
EW09-SS-012	10	**1.199**	**1.199**	2.3	7.4	9.4	10.2	10.5	10.7	10.7	10.7	10.8
EW09-SS-027	60.96	**1.212**	**1.204**	19.4	19.1	18.8	18.2	17.7	17.3	16.9	16.5	16.2
EW09-SS-038	60.96	**1.197**	**1.197**	21.3	20.1	19.1	18.2	17.4	16.7	16.0	15.4	14.9
EW09-SS-100	60.96	**1.210**	**1.199**	20.0	19.6	19.1	18.3	17.6	16.9	16.3	15.8	15.3
EW09-SS-101	60.96	**1.197**	**1.197**	62.5	57.3	52.7	48.5	44.7	41.3	38.2	35.5	32.9
EW09-SS-110	60.96	**1.197**	**1.197**	11.3	11.1	11.0	10.9	10.8	10.7	10.7	10.6	10.5
EW09-SS-114	60.96	**1.197**	**1.197**	14.4	13.9	13.6	13.2	12.9	12.6	12.3	12.1	11.9
EW09-SS-126	60.96	**1.208**	**1.201**	7.5	8.2	8.9	9.1	9.4	9.6	9.8	9.9	10.1
EW09-SS-211	60.96	**1.197**	**1.197**	51.9	47.8	44.0	40.7	37.7	35.0	32.5	30.3	28.3
EW09-SS-219	60.96	**1.197**	**1.197**	3.5	4.1	4.7	5.2	5.7	6.1	6.5	6.8	7.1
EW-109	60.96	**1.197**	**1.197**	13.8	13.4	13.0	12.7	12.5	12.2	12.0	11.8	11.6
EW-128	10	**1.201**	**1.204**	48.1	26.2	17.4	15.8	15.2	15.0	14.9	14.8	14.8
EW-132	60.96	**1.197**	**1.197**	18.8	17.9	17.1	16.4	15.8	15.2	14.7	14.2	13.8
EW-135	60.96	**1.223**	**1.208**	87.5	81.0	75.1	69.4	64.2	59.5	55.3	51.4	48.0
EW-136	60.96	**1.212**	**1.201**	31.3	29.7	28.4	26.8	25.3	24.1	22.9	21.8	20.9
EW-138	60.96	**1.197**	**1.197**	47.5	43.8	40.5	37.5	34.8	32.4	30.2	28.2	26.4
LSO-01	60.96	**1.223**	**1.208**	2313	2083	1876	1692	1526	1376	1242	1120	1011

1,4-DCB (mg/kg OC)[1]				Years Post-construction								
	Mixing Depth	1-year Deposition (cm)		Current Conditions			Future Conditions					
Point	(cm)	Current	Future[1]	0	5	10	15	20	25	30	35	40
EW09-SS-010	10	**1.356**	**1.347**	0.63	0.95	1.06	1.06	1.06	1.06	1.06	1.06	1.06
EW09-SS-012	10	**1.199**	**1.199**	0.36	0.21	0.15	0.12	0.11	0.11	0.11	0.11	0.11
EW09-SS-027	60.96	**1.212**	**1.204**	0.38	0.35	0.33	0.31	0.29	0.28	0.26	0.25	0.24
EW09-SS-038	60.96	**1.197**	**1.197**	28.75	25.94	23.40	21.11	19.05	17.19	15.51	14.00	12.63
EW09-SS-100	60.96	**1.210**	**1.199**	1.50	1.37	1.25	1.13	1.03	0.94	0.86	0.78	0.72
EW09-SS-101	60.96	**1.197**	**1.197**	263	237	214	193	174	157	141	127	115
EW09-SS-110	60.96	**1.197**	**1.197**	1.06	0.97	0.88	0.81	0.74	0.67	0.62	0.57	0.52
EW09-SS-114	60.96	**1.197**	**1.197**	0.63	0.57	0.53	0.48	0.45	0.41	0.38	0.35	0.33
EW09-SS-126	60.96	**1.208**	**1.201**	1.75	1.59	1.45	1.32	1.20	1.09	0.99	0.91	0.83
EW09-SS-211	60.96	**1.197**	**1.197**	0.63	0.57	0.53	0.48	0.45	0.41	0.38	0.35	0.33
EW09-SS-219	60.96	**1.197**	**1.197**	0.38	0.35	0.33	0.31	0.29	0.27	0.25	0.24	0.22
EW-109	60.96	**1.197**	**1.197**	1.94	1.76	1.59	1.45	1.31	1.20	1.09	0.99	0.90
EW-128	10	**1.201**	**1.204**	0.13	0.12	0.12	0.13	0.14	0.14	0.15	0.15	0.15
EW-132	60.96	**1.197**	**1.197**	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
EW-135	60.96	**1.223**	**1.208**	0.13	0.14	0.16	0.16	0.16	0.16	0.16	0.16	0.16
EW-136	60.96	**1.212**	**1.201**	0.12	0.13	0.14	0.14	0.14	0.14	0.13	0.13	0.13
EW-138	60.96	**1.197**	**1.197**	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.10
LSO-01	60.96	**1.223**	**1.208**	1.25	1.16	1.07	0.98	0.90	0.83	0.76	0.70	0.65

Table 8

Concentrations at Point Locations - Years 0 to 40 Post-construction

Arsenic (mg/kg)				Years Post-construction								
	Mixing Depth	1-year Deposition (cm)		Current Conditions			Future Conditions					
Point	(cm)	Current	Future[1]	0	5	10	15	20	25	30	35	40
EW09-SS-010	10	**1.356**	**1.347**	8.4	8.9	9.1	9.1	9.1	9.2	9.2	9.2	9.2
EW09-SS-012	10	**1.199**	**1.199**	6.0	7.8	8.6	8.9	9.0	9.0	9.0	9.0	9.0
EW09-SS-027	60.96	**1.212**	**1.204**	12.1	11.8	11.5	11.3	11.1	10.9	10.7	10.5	10.4
EW09-SS-038	60.96	**1.197**	**1.197**	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
EW09-SS-100	60.96	**1.210**	**1.199**	6.8	7.0	7.2	7.4	7.6	7.7	7.8	8.0	8.1
EW09-SS-101	60.96	**1.197**	**1.197**	7.5	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4
EW09-SS-110	60.96	**1.197**	**1.197**	9.2	9.2	9.2	9.2	9.1	9.1	9.1	9.1	9.1
EW09-SS-114	60.96	**1.197**	**1.197**	22.7	21.4	20.2	19.1	18.1	17.2	16.4	15.7	15.0
EW09-SS-126	60.96	**1.208**	**1.201**	6.4	6.7	6.9	7.1	7.3	7.5	7.6	7.8	7.9
EW09-SS-211	60.96	**1.197**	**1.197**	3.6	4.1	4.6	5.1	5.4	5.8	6.1	6.4	6.7
EW09-SS-219	60.96	**1.197**	**1.197**	3.1	3.7	4.2	4.7	5.1	5.5	5.8	6.2	6.4
EW-109	60.96	**1.197**	**1.197**	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
EW-128	10	**1.201**	**1.204**	20.0	13.4	10.8	9.7	9.3	9.2	9.1	9.1	9.1
EW-132	60.96	**1.197**	**1.197**	8.0	8.1	8.2	8.3	8.4	8.4	8.5	8.5	8.6
EW-135	60.96	**1.223**	**1.208**	12.0	11.7	11.4	11.2	11.0	10.8	10.6	10.5	10.3
EW-136	60.96	**1.212**	**1.201**	10.0	9.9	9.8	9.7	9.7	9.6	9.6	9.5	9.5
EW-138	60.96	**1.197**	**1.197**	10.0	9.9	9.8	9.7	9.7	9.6	9.6	9.5	9.5
LSO-01	60.96	**1.223**	**1.208**	7.3	7.5	7.6	7.8	7.9	8.0	8.1	8.2	8.3

HPAH (mg/kg OC)[1]				Years Post-construction								
	Mixing Depth	1-year Deposition (cm)		Current Conditions			Future Conditions					
Point	(cm)	Current	Future[1]	0	5	10	15	20	25	30	35	40
EW09-SS-010	10	**1.356**	**1.347**	190	160	151	131	124	122	122	121	121
EW09-SS-012	10	**1.199**	**1.199**	168	117	97	89	86	84	84	84	84
EW09-SS-027	60.96	**1.212**	**1.204**	204	193	182	172	164	156	149	143	137
EW09-SS-038	60.96	**1.197**	**1.197**	265	247	231	217	203	192	181	171	163
EW09-SS-100	60.96	**1.210**	**1.199**	139	134	129	124	120	117	113	111	108
EW09-SS-101	60.96	**1.197**	**1.197**	199	187	177	168	160	152	145	139	134
EW09-SS-110	60.96	**1.197**	**1.197**	133	128	123	119	116	113	110	107	105
EW09-SS-114	60.96	**1.197**	**1.197**	106	104	102	100	98	97	96	94	93
EW09-SS-126	60.96	**1.208**	**1.201**	68	69	71	72	73	74	75	76	77
EW09-SS-211	60.96	**1.197**	**1.197**	121	118	114	111	108	106	104	102	100
EW09-SS-219	60.96	**1.197**	**1.197**	86	85	85	85	85	85	85	84	84
EW-109	60.96	**1.197**	**1.197**	388	358	331	306	284	265	247	231	216
EW-128	10	**1.201**	**1.204**	381	203	131	104	93	88	86	86	85
EW-132	60.96	**1.197**	**1.197**	186	176	167	158	151	144	138	133	128
EW-135	60.96	**1.223**	**1.208**	406	375	347	321	298	277	259	242	226
EW-136	60.96	**1.212**	**1.201**	475	437	402	371	343	317	294	274	255
EW-138	60.96	**1.197**	**1.197**	406	375	346	320	297	276	257	240	225
LSO-01	60.96	**1.223**	**1.208**	244	230	216	203	192	182	172	164	156

Table 8

Concentrations at Point Locations - Years 0 to 40 Post-construction

LPAH (mg/kg OC)[1]				Years Post-construction								
	Mixing Depth	1-year Deposition (cm)		Current Conditions			Future Conditions					
Point	(cm)	Current	Future[1]	0	5	10	15	20	25	30	35	40
EW09-SS-010	10	**1.356**	**1.347**	23.1	22.5	22.2	19.9	19.1	18.8	18.8	18.7	18.7
EW09-SS-012	10	**1.199**	**1.199**	22.5	14.2	10.9	9.5	9.0	8.8	8.7	8.6	8.6
EW09-SS-027	60.96	**1.212**	**1.204**	31.3	29.1	27.1	25.3	23.7	22.2	20.9	19.7	18.6
EW09-SS-038	60.96	**1.197**	**1.197**	21.3	20.0	18.9	17.9	16.9	16.1	15.4	14.7	14.1
EW09-SS-100	60.96	**1.210**	**1.199**	21.9	20.6	19.5	18.4	17.4	16.6	15.8	15.1	14.5
EW09-SS-101	60.96	**1.197**	**1.197**	39.4	36.3	33.6	31.2	28.9	26.9	25.1	23.5	22.0
EW09-SS-110	60.96	**1.197**	**1.197**	19.4	18.3	17.4	16.5	15.7	15.0	14.4	13.8	13.3
EW09-SS-114	60.96	**1.197**	**1.197**	15.6	14.9	14.3	13.7	13.2	12.8	12.4	12.0	11.6
EW09-SS-126	60.96	**1.208**	**1.201**	5.1	5.5	5.9	6.1	6.4	6.6	6.8	7.0	7.2
EW09-SS-211	60.96	**1.197**	**1.197**	17.5	16.6	15.8	15.1	14.5	13.9	13.4	12.9	12.5
EW09-SS-219	60.96	**1.197**	**1.197**	25.0	23.4	21.9	20.6	19.4	18.4	17.4	16.5	15.7
EW-109	60.96	**1.197**	**1.197**	76.9	70.2	64.1	58.7	53.7	49.3	45.3	41.7	38.4
EW-128	10	**1.201**	**1.204**	58.8	28.7	16.7	12.1	10.3	9.5	9.2	9.1	9.1
EW-132	60.96	**1.197**	**1.197**	25.0	23.4	21.9	20.6	19.4	18.4	17.4	16.5	15.7
EW-135	60.96	**1.223**	**1.208**	73.8	67.5	61.8	56.6	51.9	47.7	43.9	40.5	37.4
EW-136	60.96	**1.212**	**1.201**	106.3	96.7	88.0	80.2	73.2	66.9	61.1	56.0	51.3
EW-138	60.96	**1.197**	**1.197**	46.9	43.1	39.7	36.7	33.9	31.4	29.2	27.1	25.3
LSO-01	60.96	**1.223**	**1.208**	58.1	53.4	49.2	45.2	41.7	38.5	35.6	33.0	30.7

Notes:
1. TOC assumed to be 1.6% for the EW.
2. Future deposition is based on expected future source control conditions for EW Laterals.
BEHP – bis(2-ethylhexyl) phthalate
cm – centimeters
DCB – dichlorobenzene
EW – East Waterway
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligram per kilogram
OC – organic carbon
PCB – polychlorinated biphenyl

Table 9a

Chemistry Assumptions for Solids Inputs to the EW for Recontamination Potential Evaluation – Current Conditions

	Contaminant of Concern								
Input Location	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	BEHP (µg/kg dw)	1,4-DCB (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxin/Furan TEQ (ng TEQ/kg dw)
Hinds CSO									
mean[1]	5	1.71	4,000	870	680	6,700	820	260	16
median[2]	6	0.36	2,900	640	430	3,000	260	240	7.6
90th percentile[3]	9	2.57	10,000	1,900	1,500	23,000	2,000	630	37
Lander CSO									
mean[1]	2	0.21	1,800	280	250	1,000	320	11	1.8
median[2]	2	0.25	2,200	220	300	800	230	11	1.8
90th percentile[3]	2	0.26	2,700	500	380	1,700	560	18	2.6
Hanford #2 CSO									
mean[1]	6	2.00	3,900	880	670	7,700	990	270	30
median[2]	6	0.72	3,100	670	540	3,300	320	250	30
90th percentile[3]	9	2.94	6,200	1,600	930	27,000	2,300	510	44
Nearshore SDs[4]									
mean[1]	10	0.09	5,500	1,000	820	8,300	75	160	15
median[2]	10	0.08	4,400	740	550	6,200	17	39	7.9
90th percentile[3]	15	0.14	14,000	1,900	2,100	19,000	180	440	32
S Lander St SD									
mean[1]	9	0.15	14,000	2,600	2,100	12,000	110	120	68
median[2]	10	0.13	5,500	810	670	9,300	90	53	68
90th percentile[3]	20	0.29	17,000	3,400	2,400	21,000	200	280	93
Non-nearshore SDs[5]									
mean[1]	10	0.19	10,000	2,000	1,400	19,000	140	290	68
median[2]	7	0.12	4,000	680	450	9,400	90	58	68
90th percentile[3]	20	0.32	11,000	3,400	1,700	24,000	280	460	93
LDW Laterals[6]									
base	13	0.14	3,900	880	1,400	15,475	990	300	20
low bounding	9	n/a	n/a	n/a	500	n/a	n/a	100	10
high bounding	30	n/a	n/a	n/a	3,400	n/a	n/a	1,000	40
LDW Bed[6]									
base	16	0.53	3,800	700	390	590	23	350	26
Green River									
base	9	0.10	1,300	130	135	120	1.20	42	6
low bounding	7	0.06	160	17	40	75	0.84	5	2
high bounding	10	0.20	1,900	230	270	210	1.30	80	8

Notes:
1. Mean chemistry values are used for Base Case scenarios.
2. Median chemistry values are used for Low Bounding Case scenarios.
3. 90th percentile chemistry values are used for High Bounding Case scenarios.
4. Nearshore SDs include SW Florida St SD (B-21), B-25, all Port SDs, and all private SDs along the waterfront (A-6, B-40, B-41, B-42, and B-43).
5. Non-nearshore SDs include S Hinds St SD, SW Spokane St EOF/SD (B-5), SW Spokane St SD (B-4), S Spokane St SD (B-36), and all bridges (BR-2, BR-4, BR-34, and BR-39).
6. Values for LDW Bed and Laterals are taken from the LDW FS (AECOM 2012).

See EW FS Appendix B, Part 4 for details on EW lateral chemistry analysis, and EW FS Appendix B, Part 3 for Green River chemistry.

µg/kg – microgram per kilogram; BEHP – bis(2-ethylhexyl) phthalate; cPAH – carcinogenic polycyclic aromatic hydrocarbon; CSO – combined sewer overflow; DCB – dichlorobenzene; dw – dry weight; EOF – emergency overflow; EW – East Waterway; FS – Feasibility Study; HPAH- – high-molecular-weight polycyclic aromatic hydrocarbon; LDW – Lower Duwamish Waterway; LPAH – low-molecular-weight polycyclic aromatic hydrocarbon; mg/kg – milligram per kilogram; ng – nanogram; PCB – polychlorinated biphenyl; SD – storm drain; TEQ – toxicity equivalent

Table 9b

Chemistry Assumptions for Solids Inputs to the EW for Recontamination Potential Evaluation – Future Source Control Conditions

Input Location	Contaminant of Concern								
	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	BEHP (µg/kg dw)	1,4-DCB (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxin/Furan TEQ (ng TEQ/kg dw)
Hinds CSO (same as current conditions)									
mean[1]	5	1.71	4,000	870	680	6,700	820	260	16
median[2]	6	0.36	2,900	640	430	3,000	260	240	7.6
90th percentile[3]	9	2.57	10,000	1,900	1,500	23,000	2,000	630	37
Lander CSO (same as current conditions)									
mean[1]	2	0.21	1,800	280	250	1,000	320	11	1.8
median[2]	2	0.25	2,200	220	300	800	230	11	1.8
90th percentile[3]	2	0.26	2,700	500	380	1,700	560	18	2.6
Hanford #2 CSO (same as current conditions)									
mean[1]	6	2.00	3,900	880	670	7,700	990	270	30
median[2]	6	0.72	3,100	670	540	3,300	320	250	30
90th percentile[3]	9	2.94	6,200	1,600	930	27,000	2,300	510	44
Nearshore SDs (same as current conditions)									
mean[1]	10	0.09	5,500	1,000	820	8,300	75	160	15
median[2]	10	0.08	4,400	740	550	6,200	17	39	7.9
90th percentile[3]	15	0.14	14,000	1,900	2,100	19,000	180	440	32
S Lander St SD (values in BOLD are different than current conditions, all other values same as current conditions)									
mean[1]	9	0.15	**8,600**	**1,600**	2,100	12,000	110	120	**22**
median[2]	10	0.13	5,500	810	670	9,300	90	53	**12**
90th percentile[3]	20	0.29	17,000	3,400	2,400	21,000	200	280	**37**
Non-nearshore SDs (values in BOLD are different than current conditions, all other values same as current conditions)									
mean[1]	**10**	0.16	**6,800**	**1,600**	**930**	**14,000**	140	**200**	**22**
median[2]	**7**	0.12	4,000	680	450	9,400	90	58	**12**
90th percentile[3]	**20**	0.32	11,000	3,400	**1,600**	24,000	**260**	460	**37**
LDW Laterals[6] (same as current conditions)									
base	13	0.14	3,900	880	1,400	15,475	990	300	20
low bounding	9	n/a	n/a	n/a	500	n/a	n/a	100	10
high bounding	30	n/a	n/a	n/a	3,400	n/a	n/a	1,000	40
LDW Bed[6] (same as current conditions)									
base	16	0.53	3,800	700	390	590	23	350	26
Green River (same as current conditions)									
base	9	0.10	1,300	130	135	120	1.20	42	6
low bounding	7	0.06	160	17	40	75	0.84	5	2
high bounding	10	0.20	1,900	230	270	210	1.30	80	8

Notes:
1. Mean chemistry values are used for Base Case scenarios.
2. Median chemistry values are used for Low Bounding Case scenarios.
3. 90th percentile chemistry values are used for High Bounding Case scenarios.
4. Nearshore SDs include SW Florida St SD (B-21), B-25, all Port SDs, and all private SDs along the waterfront (A-6, B-40, B-41, B-42, and B-43).
5. Non-nearshore SDs include S Hinds St SD, SW Spokane St EOF/SD (B-5), SW Spokane St SD (B-4), S Spokane St SD (B-36), and all bridges (BR-2, BR-4, BR-34, and BR-39).
6. Values for LDW Bed and Laterals are taken from the LDW FS (AECOM 2012).

Values are the same as current conditions (grey text) except where noted (**bold black text**).

See EW FS Appendix B, Part 4 for details on EW lateral chemistry analysis, and EW FS Appendix B, Part 3 for Green River chemistry.

µg/kg – microgram per kilogram; BEHP – bis(2-ethylhexyl) phthalate; cPAH – carcinogenic polycyclic aromatic hydrocarbon; CSO – combined sewer overflow; DCB – dichlorobenzene; dw – dry weight; EOF – emergency overflow; EW – East Waterway; FS – Feasibility Study; HPAH – high-molecular-weight polycyclic aromatic hydrocarbon; LDW – Lower Duwamish Waterway; LPAH – ow-molecular-weight polycyclic aromatic hydrocarbon; mg/kg – milligram per kilogram; ng – nanogram; PCB – polychlorinated biphenyl; SD – storm drain; TEQ – toxicity equivalent

Table 10
Calculation of Net Sedimentation Rates Used for Recontamination Potential Evaluation

PTM Model Simulation: Base Case Current Conditions			**PTM Model Simulation: Lower Bound Current Conditions**			**PTM Model Simulation: Upper Bound Current Conditions**		
Calculate total area in EW where PTM model predicts deposition of solids from EW laterals to occur over simulation period:								
Cells with Deposition	949		Cells with Deposition	710		Cells with Deposition	1086	
Area per cell	232	m^2	Area per cell	232	m^2	Area per cell	232	m^2
Total Area of Footprint:	220,525	m^2	Total Area of Footprint:	164,987	m^2	Total Area of Footprint:	252,361	m^2
Calculate the total mass and volume of the deposition of solids from EW lateral sources within the deposition footprint over an annual basis:								
Total Mass (kg)	84,630	per yr	Total Mass (kg)	45,475	per yr	Total Mass (kg)	114,117	per yr
Total Mass (g)	84,629,860	per yr	Total Mass (g)	45,474,710	per yr	Total Mass (g)	114,116,740	per yr
Density	1.5	g/cm^3	Density	1.5	g/cm^3	Density	1.5	g/cm^3
Volume of Solids Deposited	56,419,906	cm^3	Volume of Solids Deposited	30,316,473	cm^3	Volume of Solids Deposited	76,077,826	cm^3
Calculate the net sedimentation rate (cm/yr) of EW lateral sources in the deposition footprint (volume divided by area):								
NSR (laterals)	0.026	cm/yr		0.018	cm/yr		0.030	cm/yr
Total NSR (from upstream and EW lateral sources) taken from evaluation of geochronology core, see Section 5.1.2 in EW FS):								
NSR (Total)	1.20	cm/yr		1.20	cm/yr		1.20	cm/yr
Estimate the NSR due to upstream sources (Green River and LDW laterals) within the deposition footprint as the difference between the EW laterals NSR and the total NSR from geochronology cores:								
NSR (upstream contribution)	**1.175**	**cm/yr**	**NSR (upstream contribution)**	**1.18**	**cm/yr**	**NSR (upstream contribution)**	**1.17**	**cm/yr**

Notes:
cm – centimeters
cm^3 – cubic centimeters
EW – East Waterway
FS – Feasibility Study
g – gram
kg – kilogram
LDW – Lower Duwamish Waterway
m^2 – square meters
NSR – net sedimentation rate
PTM – particle tracking model
yr – year

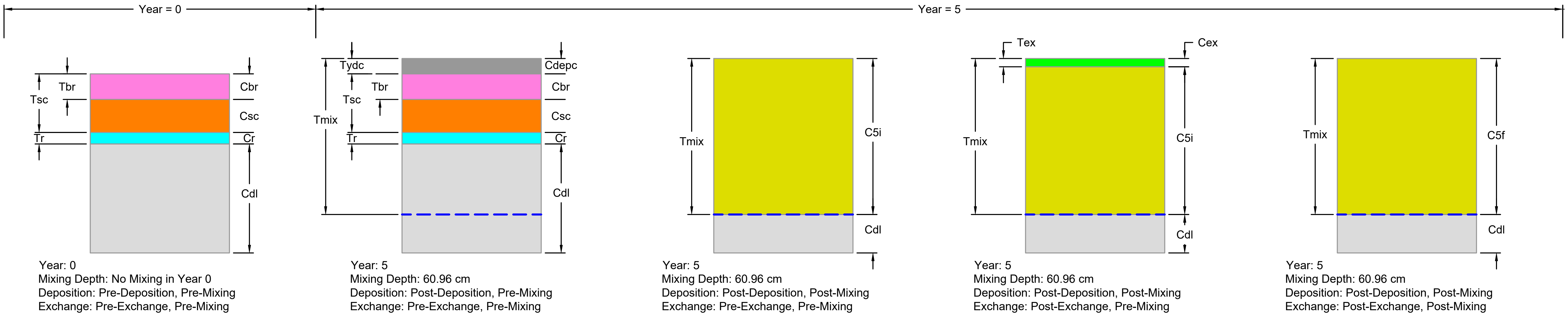
Table 11

Bounding Scenarios for Recontamination Potential Evaluation

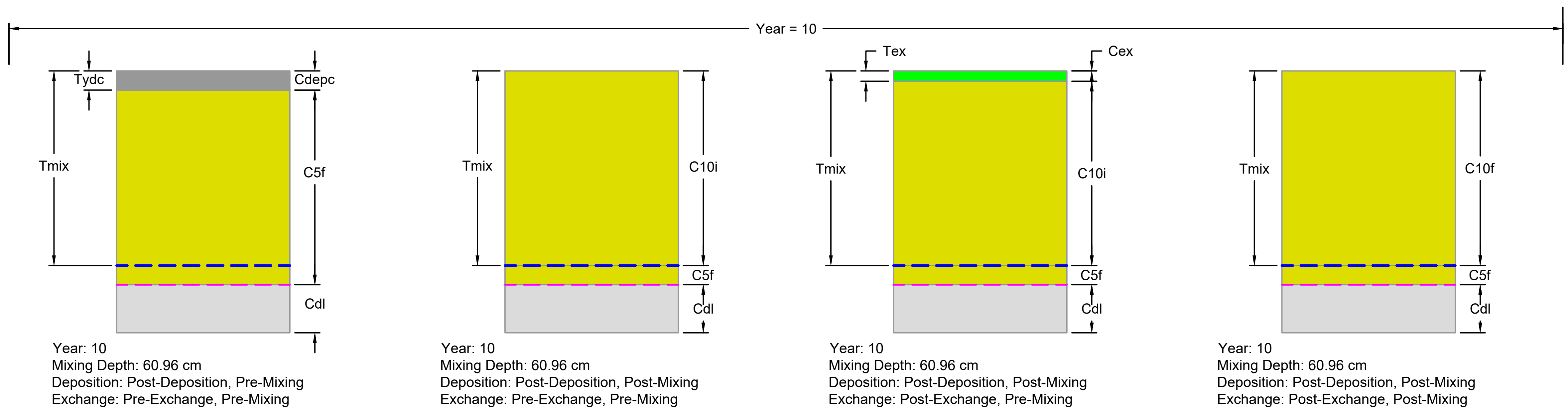
Scenario	COC	EW Lateral Deposition[1]	EW Lateral Chemistry[2]	Upstream Deposition[3]	Upstream Chemistry[4]
1a	PCBs	High bound	High bound	1.175 cm/yr (Base)	Base/Mean
1b	PCBs	Low bound	Low bound		
2a	Dioxins/Furans	High bound	High bound		
2b	Dioxins/Furans	Low bound	Low bound		
3a	BEHP	High bound	High bound		
3b	BEHP	Low bound	Low bound		

Notes:
1. EW Lateral Deposition details can be found in Section 4.2 of Appendix J, and Figures 7 to 12 of FS Appendix B.
2. EW Lateral Chemistry details can be found in Section 4.2 and Tables 9a and 9b of Appendix J.
3. Upstream Deposition details can be found in Section 4.2 and Table 10 of Appendix J.
4. Upstream Chemistry details can be found in Section 4.2 and Tables 9a and 9b of Appendix J.
BEHP – bis(2-ethylhexyl)phthalate
cm/yr – centimeters per year
COC – contaminant of concern
EW – East Waterway
FS – Feasibility Study
PCB – polychlorinated biphenyl

FIGURES



NOTES:
1. The maximum Mixing Depth is illustrated on this figure; additional mixing depths may be used in the analyses.
2. Illustrations are not to scale.
3. See Figure 1-b for additional years.



LEGEND
- Bed Replacement Layer
- Residuals Management Cover (RMC) Layer
- Dredge Residuals Layer
- In-Situ Sediment Below Dredge Neatline
- Depositional Sediment Layer
- Exchanged Under-Pier Depositional Layer
- Homogeneous Mixed Sediment Layer
- Vertical Limit of Mix Depth
- Vertical Limit of Previous Mix Depth

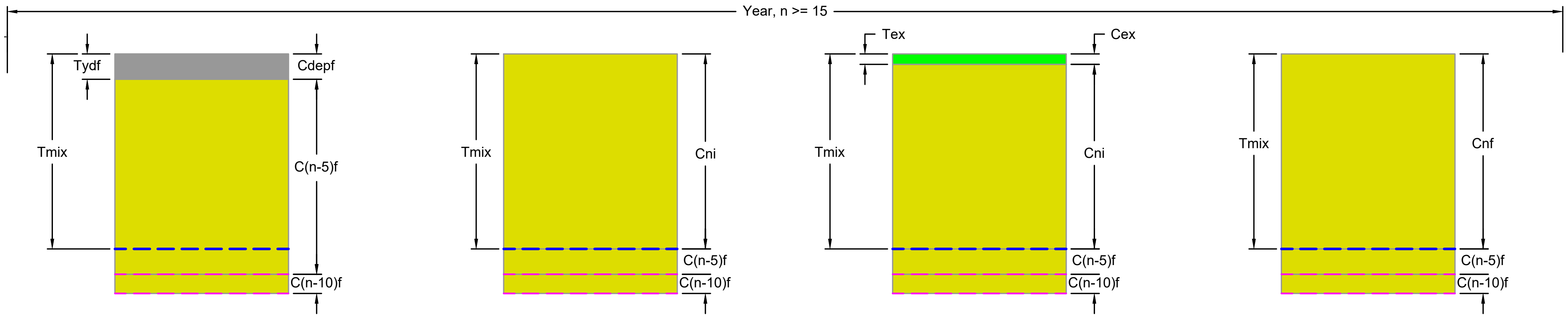
CONCENTRATION VARIABLES

Cbr	Conc. of Bed Replacement Layer
Csc	Conc. of Residuals Management Cover (RMC)
Cr	Conc. of Dredge Residual Sediment
Cdl	Conc. of In-Situ Sediment Below Dredge Neatline
Cdepc	Conc. of Depositional Sediment (Current Conditions)
Cex	Conc. of Exchanged Sediment (Under-Pier / Open-Water)
Cni	Conc. of Mixed Sediments at Year n, Intermediate Value
Cnf	Conc. of Mixed Sediments at Year n, Final Value

DEPTH VARIABLES

Tbr	Depth of Bed Replacement Layer (10 cm)
Tsc	Depth of Residuals Management Cover (RMC, 9 in = 23 cm)
Tr	Depth of Dredge Residual Sediment (5.1 cm minus 10% loss during placement for the base case)
Tydc	Depth of Depositional Sediment (Current Conditions, 1.2 cm/ year for the base case)
Tex	Depth of Exchanged Sediment (Under-Pier / Open-Water, 0.4 cm to 2 cm per year depending on the alternative)
Tmix	Vertical Depth of Mixing (10 cm to 61 cm depending on the location; 61 cm shown in this example)

Figure 1a
Box Model: Removal Through Year 10
Feasibility Study - Appendix J
East Waterway Study Area



Year: n >=15
Mixing Depth: 60.96 cm
Deposition: Post-Deposition, Pre-Mixing
Exchange: Pre-Exchange, Pre-Mixing

Year: n >=15
Mixing Depth: 60.96 cm
Deposition: Post-Deposition, Post-Mixing
Exchange: Pre-Exchange, Pre-Mixing

Year: n >=15
Mixing Depth: 60.96 cm
Deposition: Post-Deposition, Post-Mixing
Exchange: Post-Exchange, Pre-Mixing

Year: n >=15
Mixing Depth: 60.96 cm
Deposition: Post-Deposition, Post-Mixing
Exchange: Post-Exchange, Post-Mixing

NOTES:
1. The maximum Mixing Depth is illustrated on this figure; additional mixing depths may be used in the analyses.
2. Illustrations are not to scale.
3. See other Figures for years 0 through 10; applies to Figures 1a, 1c, 1d, 1e, and 1j.

DEPTH VARIABLES

Tbr	Depth of Bed Replacement Layer (10 cm)
Tsc	Depth of Residuals Management Cover (RMC, 9 in = 23 cm)
Tr	Depth of Dredge Residual Sediment (5.1 cm minus 10% loss during placement for the base case)
Tydc	Depth of Depositional Sediment (Current Conditions, 1.2 cm/ year for the base case)
Tex	Depth of Exchanged Sediment (Under-Pier / Open-Water, 0.4 cm to 2 cm per year depending on the alternative)
Tmix	Vertical Depth of Mixing (10 cm to 61 cm depending on the location; 61 cm shown in this example)

LEGEND

Depositional Sediment Layer
Exchanged Under-Pier Depositional Layer
Homogeneous Mixed Sediment Layer
Vertical Limit of Mix Depth
Vertical Limit of Previous Mix Depth

CONCENTRATION VARIABLES

Cdepf	Conc. of Depositional Sediment (Future Conditions)
Cex	Conc. of Exchanged Sediment (Under-Pier / Open-Water)
Cni	Conc. of Mixed Sediments at Year n, Intermediate Value
Cnf	Conc. of Mixed Sediments at Year n, Final Value

DEPTH VARIABLES

Tydf	Depth of Depositional Sediment (Future Conditions, 1.2 cm/ year for the base case)
Tex	Depth of Exchanged Sediment (Under-Pier / Open-Water, 0.4 cm to 2 cm per year depending on the alternative)
Tmix	Vertical Depth of Mixing (10 cm to 61 cm depending on the location; 61 cm shown in this example)

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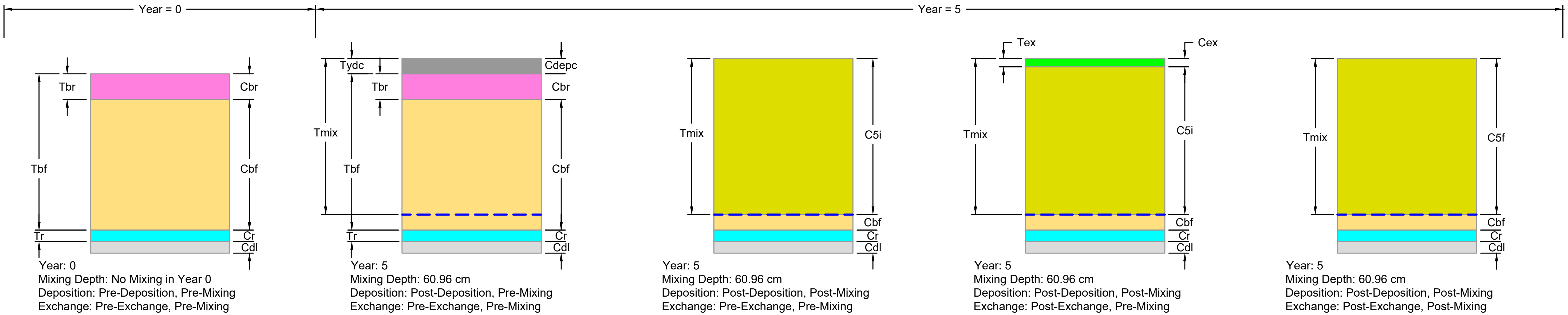
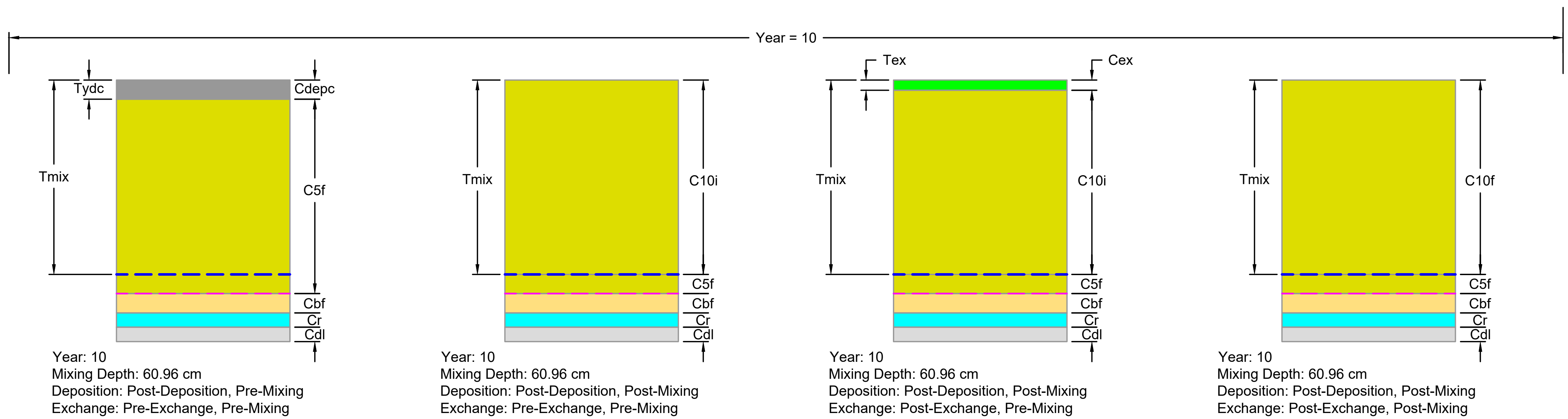
Figure 1b
Box Model: Select Remedies Beyond Year 10
Feasibility Study - Appendix J
East Waterway Study Area



NOTES:

1. The maximum Mixing Depth is illustrated on this figure; additional mixing depths may be used in the analyses.
2. Illustrations are not to scale.
3. See Figure 1-b for additional years.



LEGEND

- Bed Replacement Layer
- Placement Layer
- Dredge Residuals Layer
- In-Situ Sediment Below Dredge Neatline
- Depositional Sediment Layer
- Exchanged Under-Pier Depositional Layer
- Homogeneous Mixed Sediment Layer
- Vertical Limit of Mix Depth
- Vertical Limit of Previous Mix Depth

CONCENTRATION VARIABLES

Cbr	Conc. of Bed Replacement Layer
Cbf	Conc. of Placement Layer
Cr	Conc. of Dredge Residual Sediment
Cdl	Conc. of In-Situ Sediment Below Dredge Neatline
Cdepc	Conc. of Depositional Sediment (Current Conditions)
Cex	Conc. of Exchanged Sediment (Under-Pier / Open-Water)
Cni	Conc. of Mixed Sediments at Year n, Intermediate Value
Cnf	Conc. of Mixed Sediments at Year n, Final Value

DEPTH VARIABLES

Tbr	Depth of Bed Replacement Layer (10 cm)
Tbf	Depth of Backfill (Location Specific but Greater Than 61 cm Mixing Depth)
Tr	Depth of Dredge Residual Sediment (5.1 cm minus 10% loss during placement for the base case)
Tydc	Depth of Depositional Sediment (Current Conditions, 1.2 cm/ year for the base case)
Tex	Depth of Exchanged Sediment (Under-Pier / Open-Water, 0.4 cm to 2 cm per year depending on the alternative)
Tmix	Vertical Depth of Mixing (10 cm to 61 cm depending on the location; 61 cm shown in this example)

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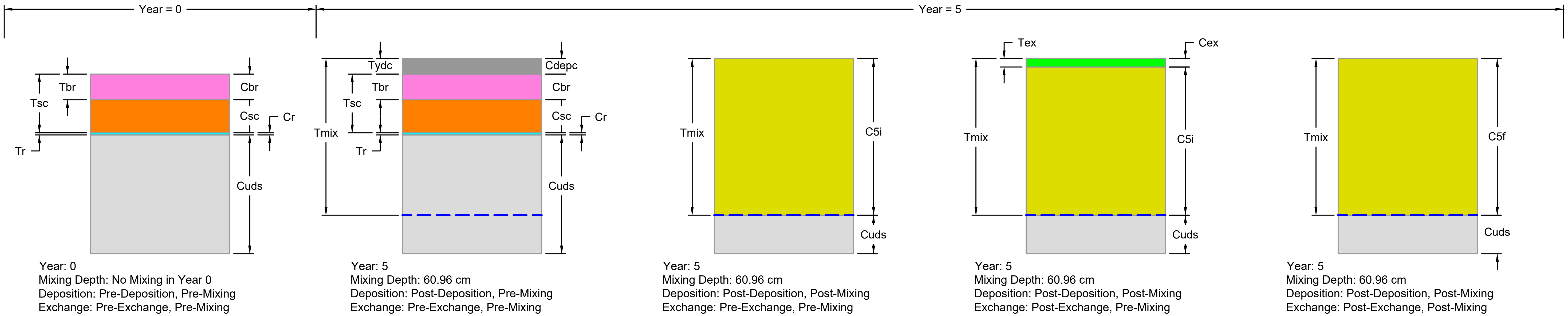
Figure 1c

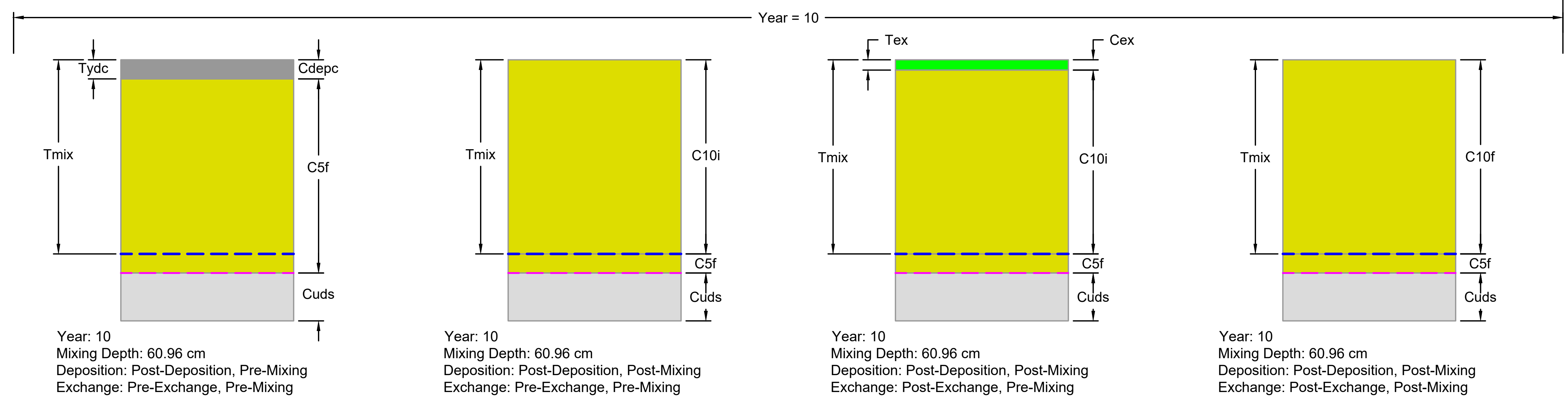
Box Model: Removal and Fill to Existing Contours Through Year 10

Feasibility Study - Appendix J

East Waterway Study Area



NOTES:
1. The maximum Mixing Depth is illustrated on this figure; additional mixing depths may be used in the analyses.
2. Illustrations are not to scale.
3. See Figure 1-b for additional years.



LEGEND

- Bed Replacement Layer
- Residuals Management Cover (RMC) Layer
- Dredge Residuals Layer
- In-Situ (Undisturbed) Sediment
- Depositional Sediment Layer
- Exchanged Under-Pier Depositional Layer
- Homogeneous Mixed Sediment Layer
- Vertical Limit of Mix Depth
- Vertical Limit of Previous Mix Depth

CONCENTRATION VARIABLES

Cbr	Conc. of Bed Replacement Layer
Csc	Conc. of Residuals Management Cover (RMC)
Cr	Conc. of Dredge Residual Sediment
Cuds	Conc. of In-Situ Undisturbed Sediment
Cdepc	Conc. of Depositional Sediment (Current Conditions)
Cex	Conc. of Exchanged Sediment (Under-Pier / Open-Water)
Cni	Conc. of Mixed Sediments at Year n, Intermediate Value
Cnf	Conc. of Mixed Sediments at Year n, Final Value

DEPTH VARIABLES

Tbr	Depth of Bed Replacement Layer (10 cm)
Tsc	Depth of Residuals Management Cover (RMC, 9 in = 23 cm)
Tr	Depth of Dredge Residual Sediment (5.1 cm minus 10% loss during placement for the base case)
Tydc	Depth of Depositional Sediment (Current Conditions, 1.2 cm/ year for the base case)
Tex	Depth of Exchanged Sediment (Under-Pier / Open-Water, 0.4 cm to 2 cm per year depending on the alternative)
Tmix	Vertical Depth of Mixing (10 cm to 61 cm depending on the location; 61 cm shown in this example)

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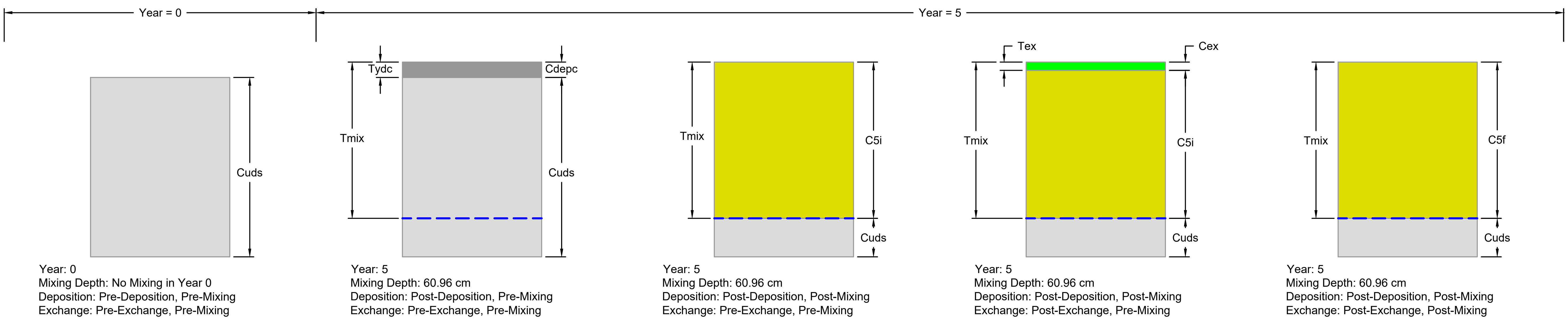
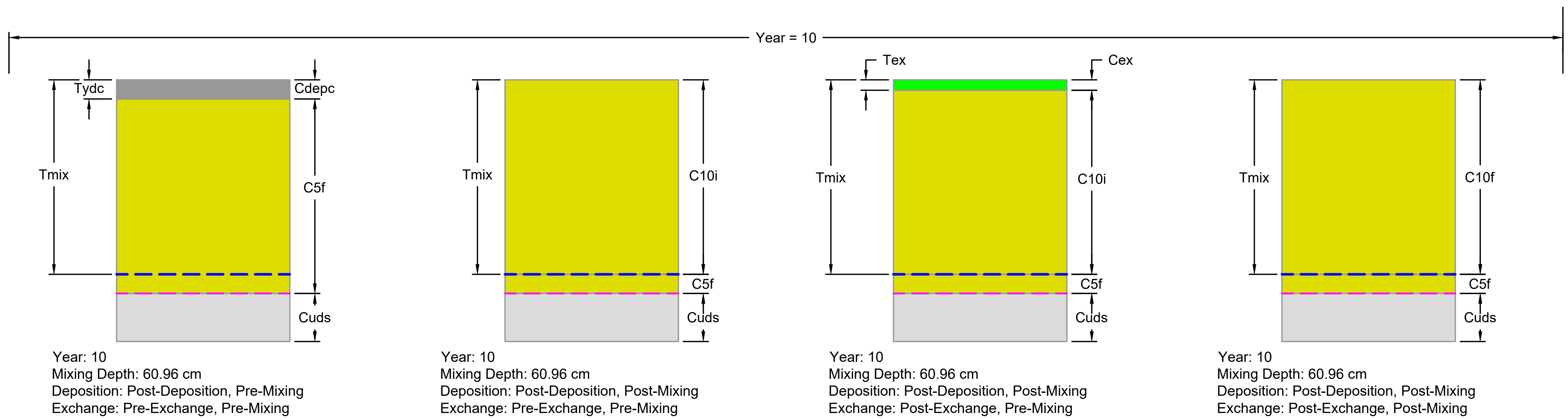
Figure 1d
Box Model: No Action (Open Water; Internal Unremediated Islands) Through Year 10
Feasibility Study - Appendix J
East Waterway Study Area



NOTES:

1. The maximum Mixing Depth is illustrated on this figure; additional mixing depths may be used in the analyses.
2. Illustrations are not to scale.
3. See Figure 1-b for additional years.



LEGEND

- In-Situ (Undisturbed) Sediment
- Depositional Sediment Layer
- Exchanged Under-Pier Depositional Layer
- Homogeneous Mixed Sediment Layer
- Vertical Limit of Mix Depth
- Vertical Limit of Previous Mix Depth

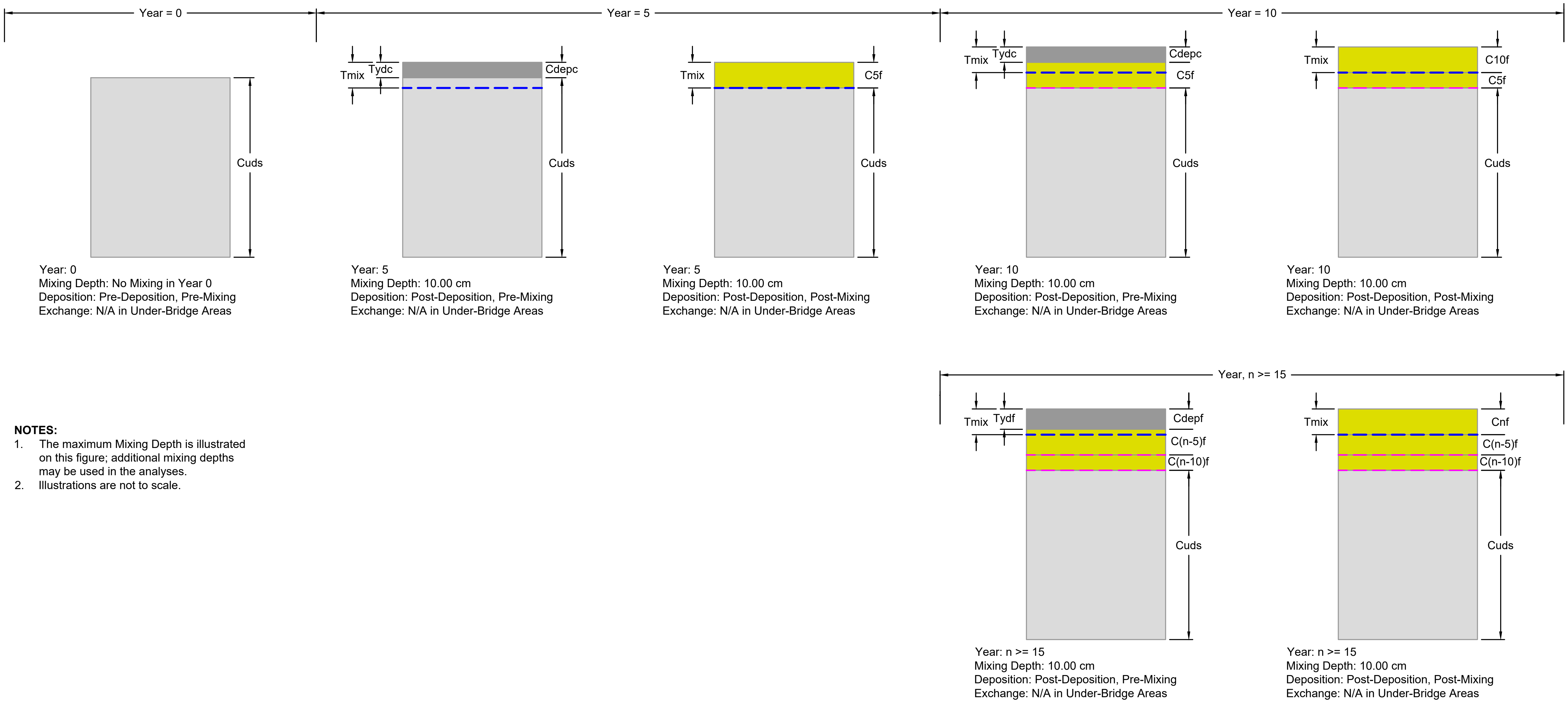
CONCENTRATION VARIABLES

Cuds	Conc. of In-Situ Undisturbed Sediment
Cdepc	Conc. of Depositional Sediment (Current Conditions)
Cex	Conc. of Exchanged Sediment (Under-Pier / Open-Water)
Cni	Conc. of Mixed Sediments at Year n, Intermediate Value
Cnf	Conc. of Mixed Sediments at Year n, Final Value

DEPTH VARIABLES

Tydc	Depth of Depositional Sediment (Current Conditions, 1.2 cm/ year for the base case)
Tex	Depth of Exchanged Sediment (Under-Pier / Open-Water, 0.4 cm to 2 cm per year depending on the alternative)
Tmix	Vertical Depth of Mixing (10 cm to 61 cm depending on the location; 61 cm shown in this example)

Figure 1e
Box Model: No Action (External Unremediated Areas) Through Year 10
Feasibility Study - Appendix J
East Waterway Study Area



NOTES:

1. The maximum Mixing Depth is illustrated on this figure; additional mixing depths may be used in the analyses.
2. Illustrations are not to scale.

LEGEND

- In-Situ (Undisturbed) Sediment
- Depositional Sediment Layer
- Homogeneous Mixed Sediment Layer
- Vertical Limit of Mix Depth
- Vertical Limit of Previous Mix Depth

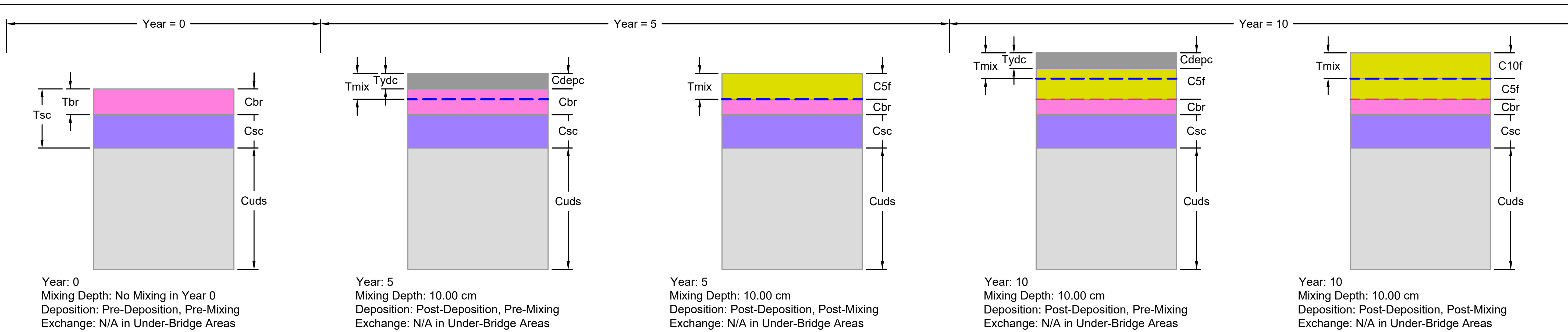
CONCENTRATION VARIABLES

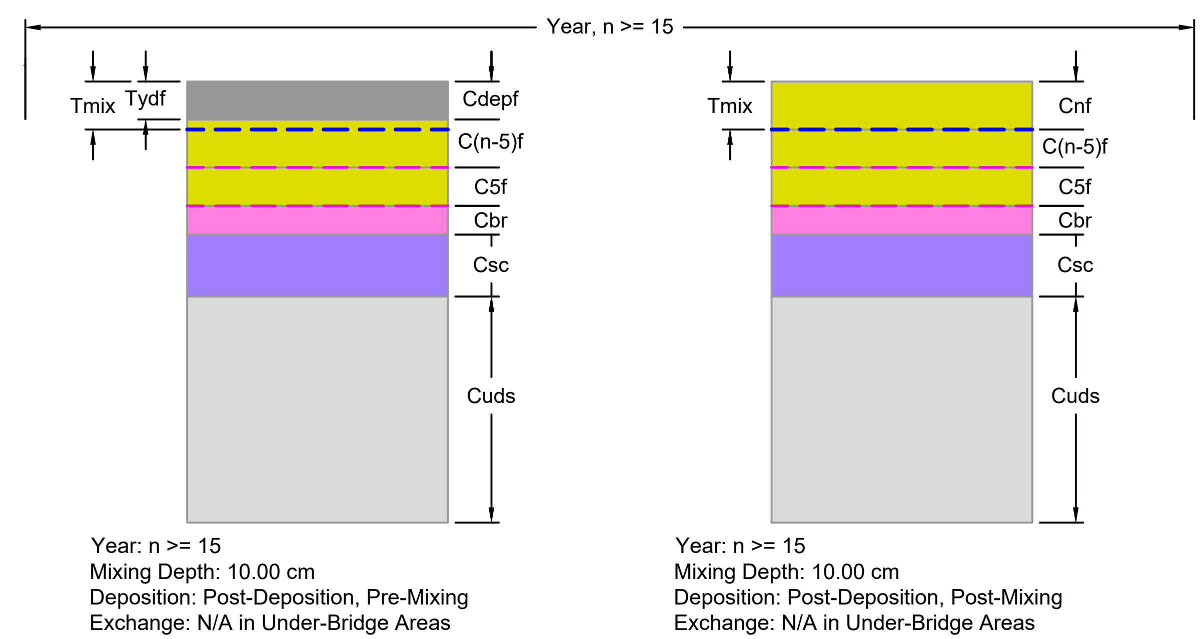
Cuds	Conc. of In-Situ Undisturbed Sediment
Cdepc	Conc. of Depositional Sediment (Current Conditions)
Cdepf	Conc. of Depositional Sediment (Future Conditions)
Cnf	Conc. of Mixed Sediments at Year n, Final Value

DEPTH VARIABLES

Tydc	Depth of Depositional Sediment (Current Conditions, 1.2 cm/ year for the base case)
Tydf	Depth of Depositional Sediment (Future Conditions, 1.2 cm/ year for the base case)
Tmix	Vertical Depth of Mixing (10 cm)

Figure 1f
Box Model: Monitored Natural Recovery (MNR) in the Sill Reach All Years
Feasibility Study - Appendix J
East Waterway Study Area





NOTES:

1. The maximum Mixing Depth is illustrated on this figure; additional mixing depths may be used in the analyses.
2. Illustrations are not to scale.

LEGEND

- Bed Replacement Layer
- Enhanced Natural Recovery (ENR) Layer
- In-Situ (Undisturbed) Sediment
- Depositional Sediment Layer
- Homogeneous Mixed Sediment Layer
- Vertical Limit of Mix Depth
- Vertical Limit of Previous Mix Depth

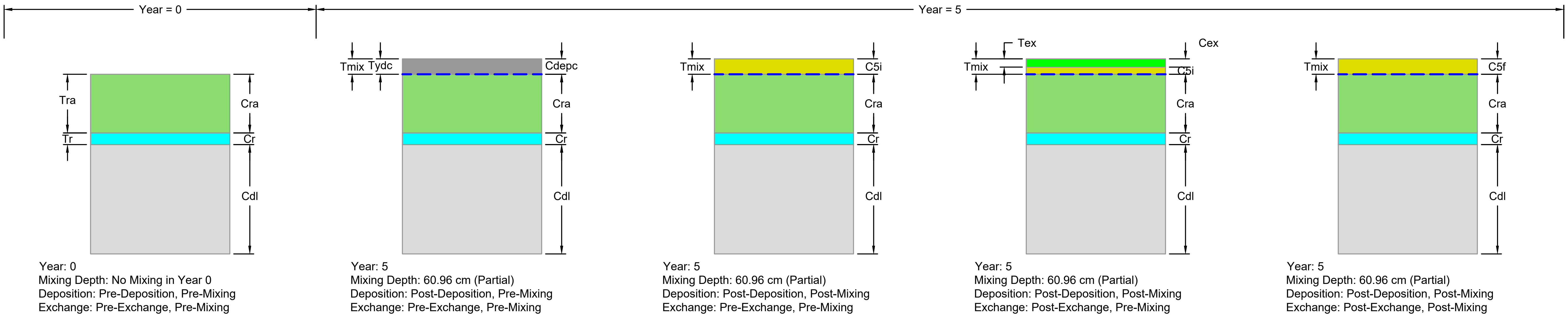
CONCENTRATION VARIABLES

Cbr	Conc. of Bed Replacement Layer
Csc	Conc. of Enhanced Natural Recovery (ENR) Layer
Cuds	Conc. of In-Situ Undisturbed Sediment
Cdepc	Conc. of Depositional Sediment (Current Conditions)
Cdepf	Conc. of Depositional Sediment (Future Conditions)
Cnf	Conc. of Mixed Sediments at Year n, Final Value

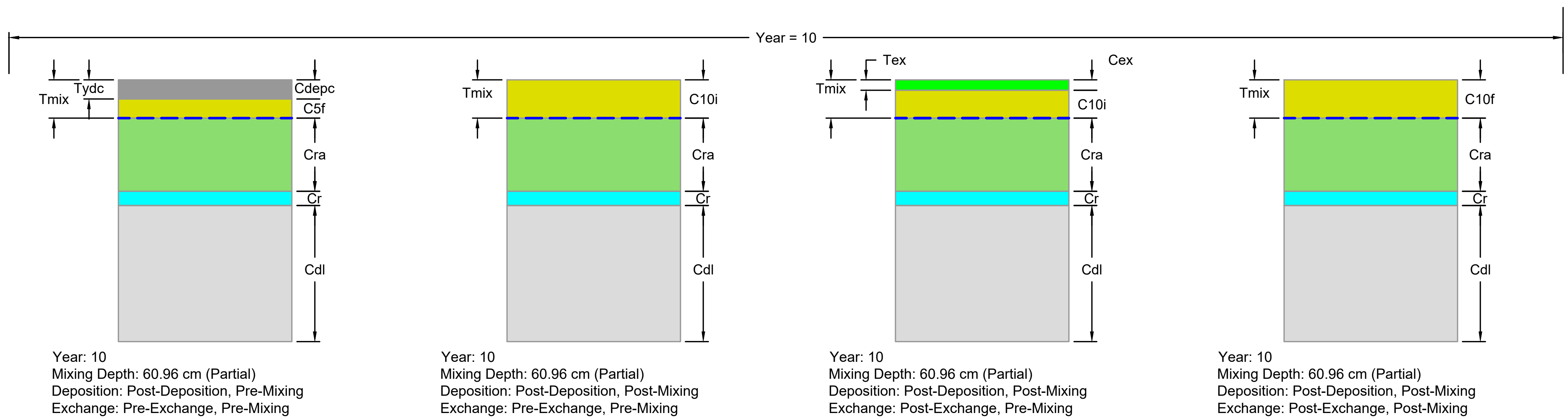
DEPTH VARIABLES

Tbr	Depth of Bed Replacement Layer (10 cm)
Tsc	Depth of Enhanced Natural Recovery (ENR) Layer (9 in = 23 cm)
Tydc	Depth of Depositional Sediment (Current Conditions, 1.2 cm/ year for the base case)
Tydf	Depth of Depositional Sediment (Future Conditions, 1.2 cm/ year for the base case)
Tmix	Vertical Depth of Mixing (10 cm)

Figure 1g
Box Model: Enhanced Natural Recovery in the Sill Reach (ENR-sill) All Years
Feasibility Study - Appendix J
East Waterway Study Area



NOTES:
1. The maximum Mixing Depth is illustrated on this figure; additional mixing depths may be used in the analyses.
2. Illustrations are not to scale.
3. Mixing depth is limited to the top of the Cap Placement Layer.
4. See Figure 1i for additional years.



LEGEND

Cap Placement Layer (Including Armor Rock)
Dredge Residuals Layer
In-Situ Sediment Below Dredge Neatline
Depositional Sediment Layer
Exchanged Under-Pier Depositional Layer
Homogeneous Mixed Sediment Layer

Vertical Limit of Mix Depth
Vertical Limit of Previous Mix Depth

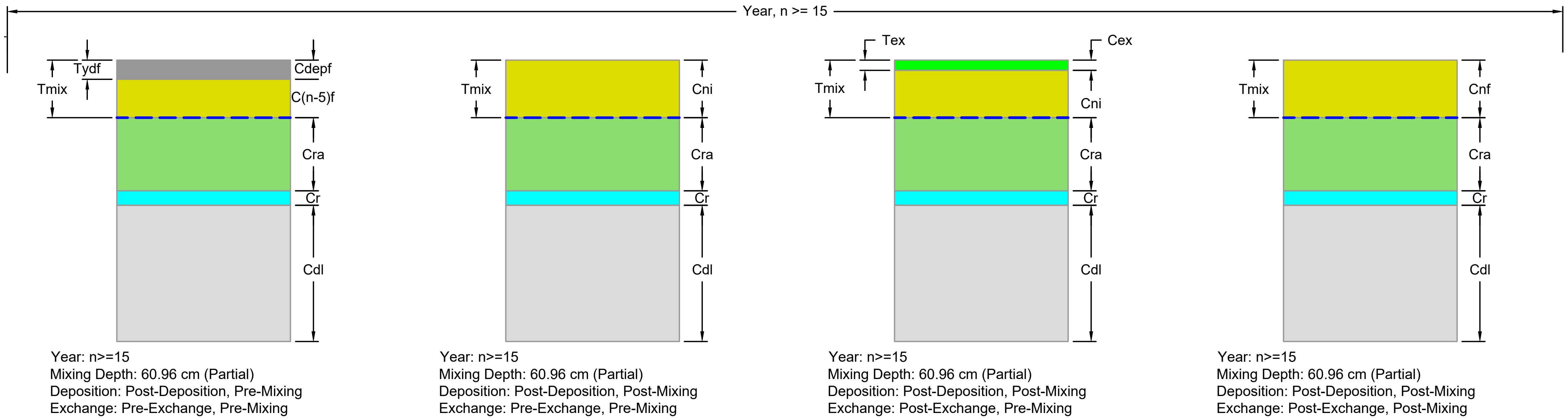
CONCENTRATION VARIABLES

Cra	Conc. of Cap Placements (Including Armor Rock)
Cr	Conc. of Dredge Residual Sediment
Cdl	Conc. of In-Situ Sediment Below Dredge Neatline
Cdepc	Conc. of Depositional Sediment (Current Conditions)
Cex	Conc. of Exchanged Sediment (Under-Pier / Open-Water)
Cni	Conc. of Mixed Sediments at Year n, Intermediate Value
Cnf	Conc. of Mixed Sediments at Year n, Final Value

DEPTH VARIABLES

Tra	Depth of Cap Placements (Including Armor Rock, depth n/a - armored)
Tr	Depth of Dredge Residual Sediment (depth n/a - isolated in armored cap)
Tydc	Depth of Depositional Sediment (Current Conditions, 1.2 cm/ year for the base case)
Tex	Depth of Exchanged Sediment (Under-Pier / Open-Water, 0.4 cm to 2 cm per year depending on the alternative)
Tmix	Vertical Depth of Mixing (up to 10 cm to 61 cm depending on the location; maximum depth of mixing down to the cap armor)

Figure 1h
Box Model: Partial Removal and Cap Through Year 10
Feasibility Study - Appendix J
East Waterway Study Area



NOTES:
1. The maximum Mixing Depth is illustrated on this figure; additional mixing depths may be used in the analyses.
2. Illustrations are not to scale.
3. Mixing depth is limited to the top of the Cap Placement Layer.
4. See Figure 1h for years 0 through 10.

LEGEND

- Cap Placement Layer (Including Armor Rock)
- Dredge Residuals Layer
- In-Situ Sediment Below Dredge Neatline
- Depositional Sediment Layer
- Exchanged Under-Pier Depositional Layer
- Homogeneous Mixed Sediment Layer
- Vertical Limit of Mix Depth
- Vertical Limit of Previous Mix Depth

CONCENTRATION VARIABLES

Cra	Conc. of Cap Placements (Including Armor Rock)
Cr	Conc. of Dredge Residual Sediment
Cdl	Conc. of In-Situ Sediment Below Dredge Neatline
Cdepf	Conc. of Depositional Sediment (Future Conditions)
Cex	Conc. of Exchanged Sediment (Under-Pier / Open-Water)
Cni	Conc. of Mixed Sediments at Year n, Intermediate Value
Cnf	Conc. of Mixed Sediments at Year n, Final Value

DEPTH VARIABLES

Tra	Depth of Cap Placements (Including Armor Rock, depth n/a - armored)
Tr	Depth of Dredge Residual Sediment (depth n/a - isolated in armored cap)
Tydf	Depth of Depositional Sediment (Future Conditions, 1.2 cm/ year for the base case)
Tex	Depth of Exchanged Sediment (Under-Pier / Open-Water, 0.4 cm to 2 cm per year depending on the alternative)
Tmix	Vertical Depth of Mixing (up to 10 cm to 61 cm depending on the location; maximum depth of mixing down to the cap armor)

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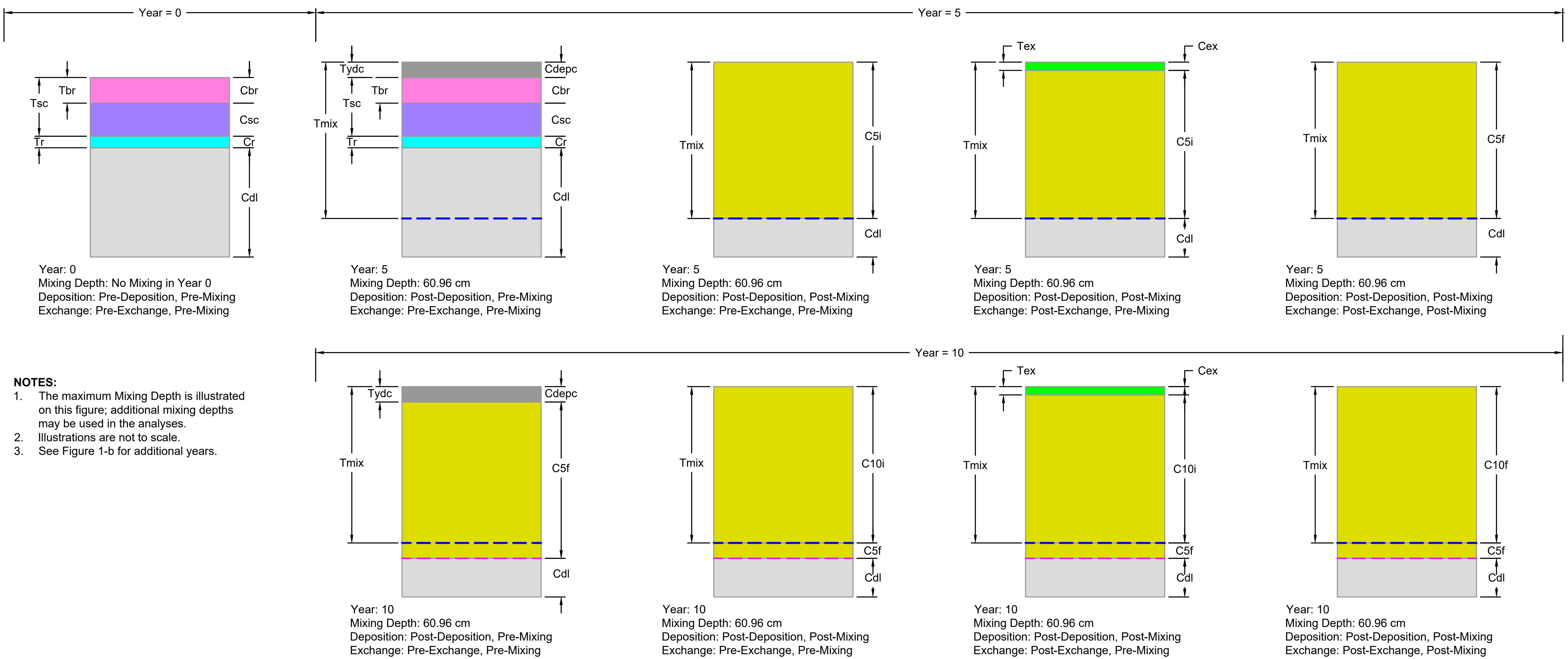
Figure 1i
Box Model: Partial Removal and Cap Beyond Year 10
Feasibility Study - Appendix J
East Waterway Study Area



NOTES:

1. The maximum Mixing Depth is illustrated on this figure; additional mixing depths may be used in the analyses.
2. Illustrations are not to scale.
3. See Figure 1-b for additional years.

LEGEND

- Bed Replacement Layer
- Enhanced Natural Recovery (ENR) Layer
- Dredge Residuals Layer
- In-Situ Sediment Below Dredge Neatline
- Depositional Sediment Layer
- Exchanged Under-Pier Depositional Layer
- Homogeneous Mixed Sediment Layer
- Vertical Limit of Mix Depth
- Vertical Limit of Previous Mix Depth

CONCENTRATION VARIABLES

Cbr	Conc. of Bed Replacement Layer
Csc	Conc. of Enhanced Natural Recovery (ENR) Layer
Cr	Conc. of Dredge Residual Sediment
Cdl	Conc. of In-Situ Sediment Below Dredge Neatline
Cdepc	Conc. of Depositional Sediment (Current Conditions)
Cex	Conc. of Exchanged Sediment (Under-Pier / Open-Water)
Cni	Conc. of Mixed Sediments at Year n, Intermediate Value
Cnf	Conc. of Mixed Sediments at Year n, Final Value

DEPTH VARIABLES

Tbr	Depth of Bed Replacement Layer (10 cm)
Tsc	Depth of Enhanced Natural Recovery (ENR) Layer (18 in = 46 cm)
Tr	Depth of Dredge Residual Sediment (in ENR-nav areas, 1.0 cm minus 10% loss during placement for the base case; in partial removal and ENR-nav areas, 5.1 cm minus 10% loss during placement for the basecase)
Tydc	Depth of Depositional Sediment (Current Conditions, 1.2 cm/ year for the base case)
Tex	Depth of Exchanged Sediment (Under-Pier / Open-Water, 0.4 cm to 2 cm per year depending on the alternative)
Tmix	Vertical Depth of Mixing (10 cm to 61 cm depending on the location; 61 cm shown in this example)

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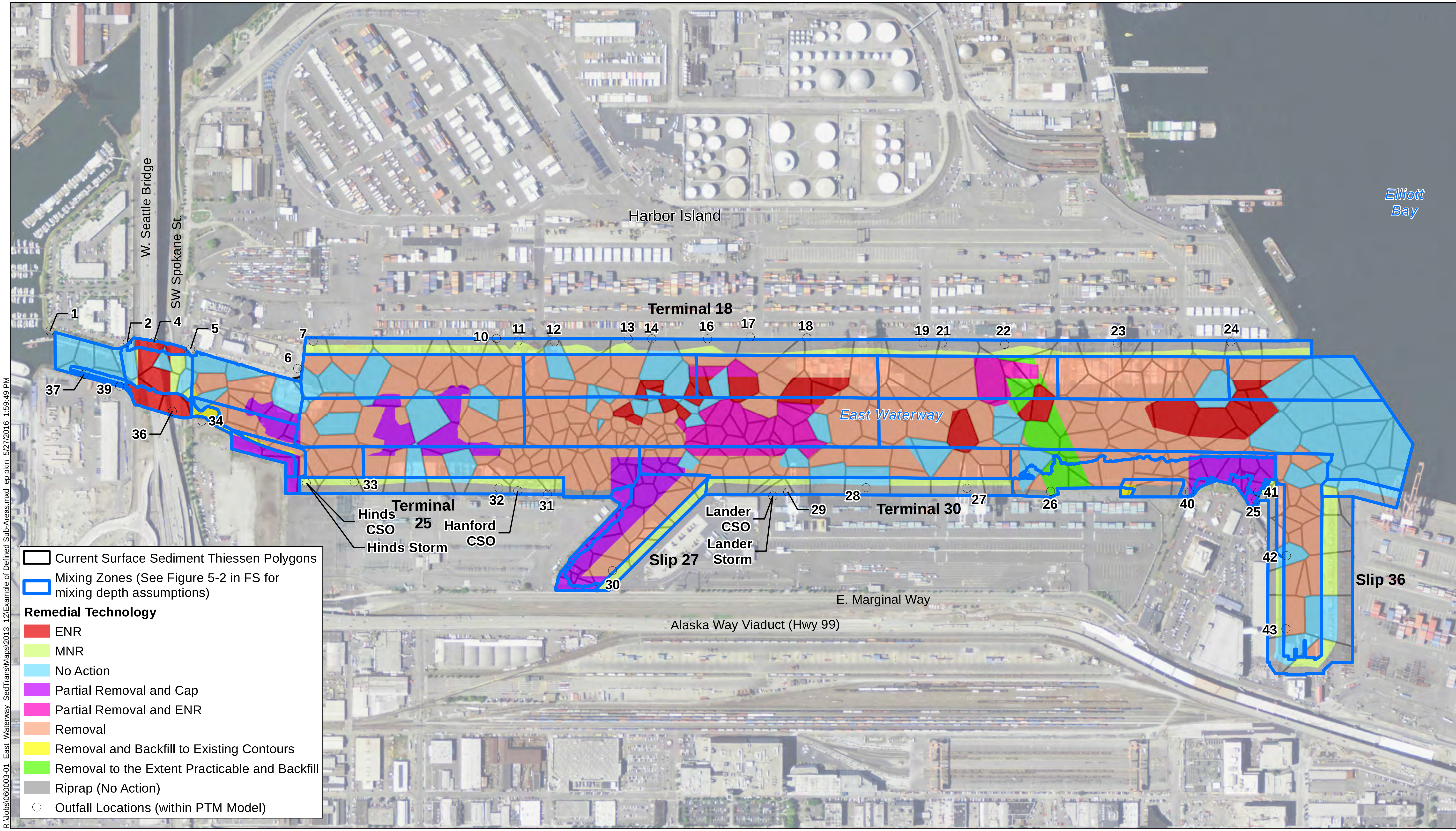
Figure 1j

Box Model: Enhanced Natural Recovery Navigation (ENR-nav) All Years

Feasibility Study - Appendix J

East Waterway Study Area



NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.
3. Remedial technology sub-areas shown are for Alternative 3 (see Map 9-2 in Section 8 of the FS).
4. Current surface sediment thiessen polygons presented are for

Figure 2
Example of Development of Box-model Sub-areas based on Alternative 1A(12)
Feasibility Study - Appendix J
East Waterway Study Area

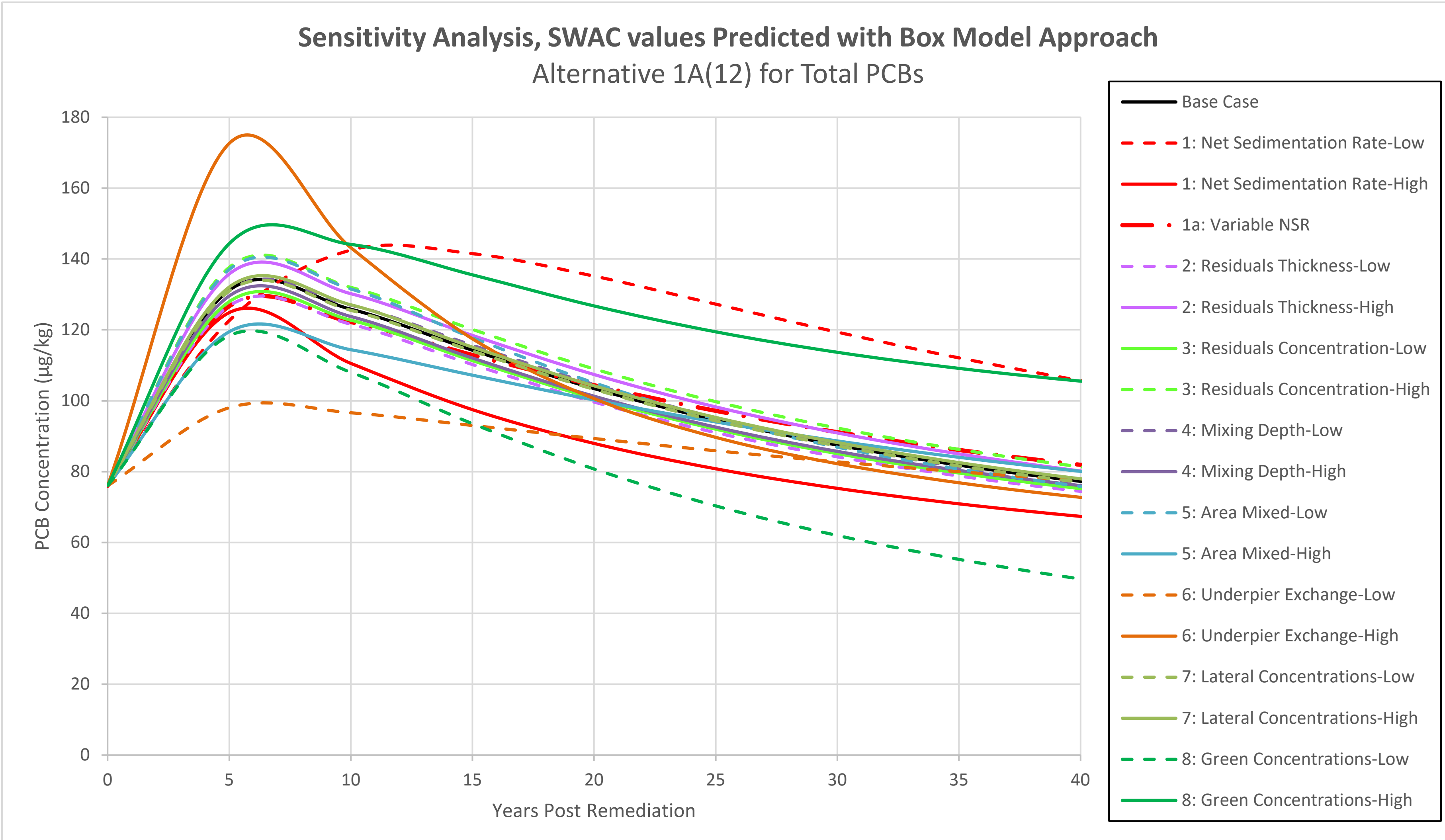


Figure 3a
Sensitivity Analysis, SWAC Values Predicted with Box Model Approach, Alternative 1A(12)
Feasibility Study - Appendix J
East Waterway Study Area

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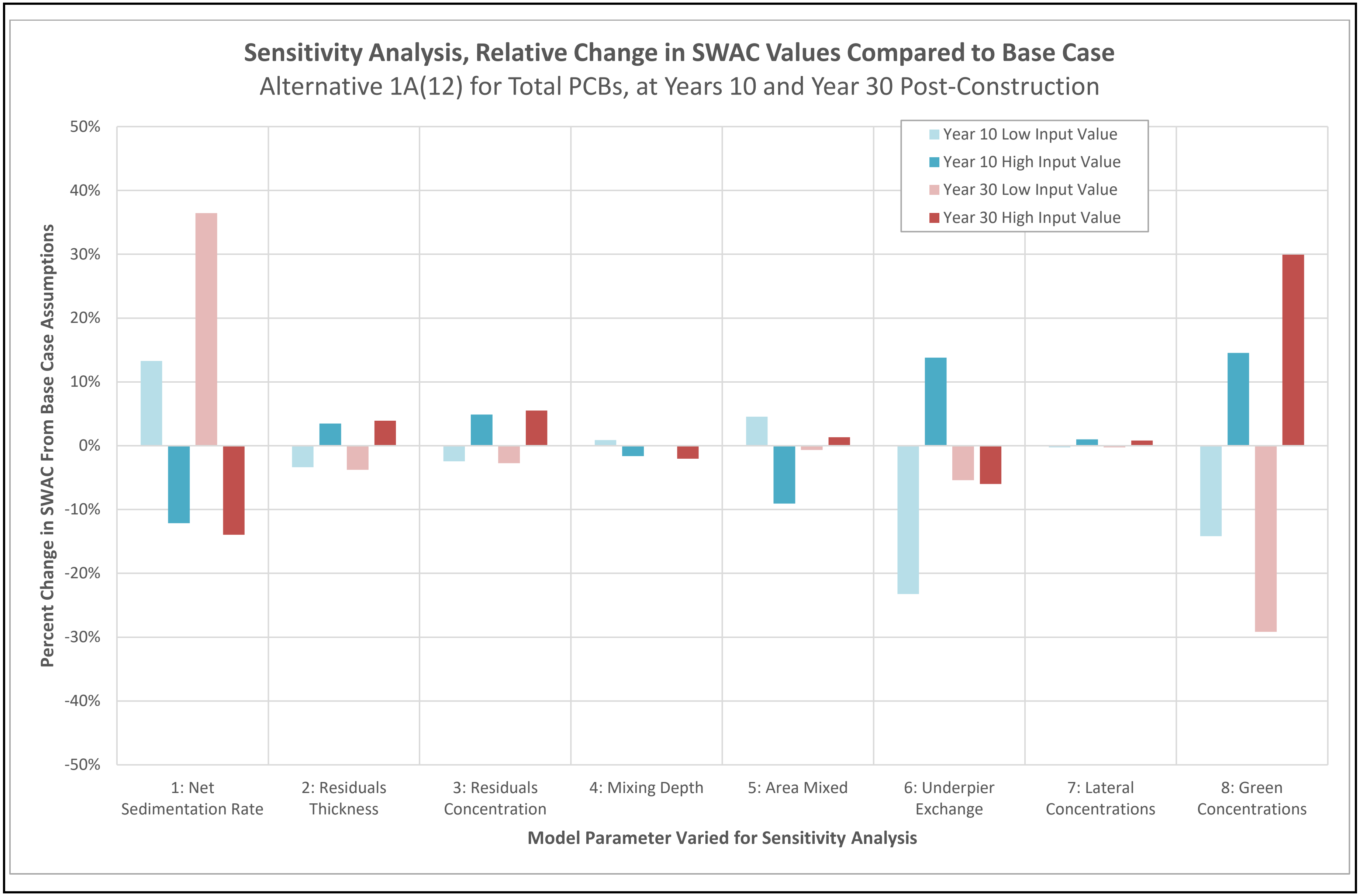


Figure 3b
Sensitivity Analysis, Relative Change in SWAC Values Compared to Base Case, Alternative 1A(12)
Feasibility Study - Appendix J
East Waterway Study Area

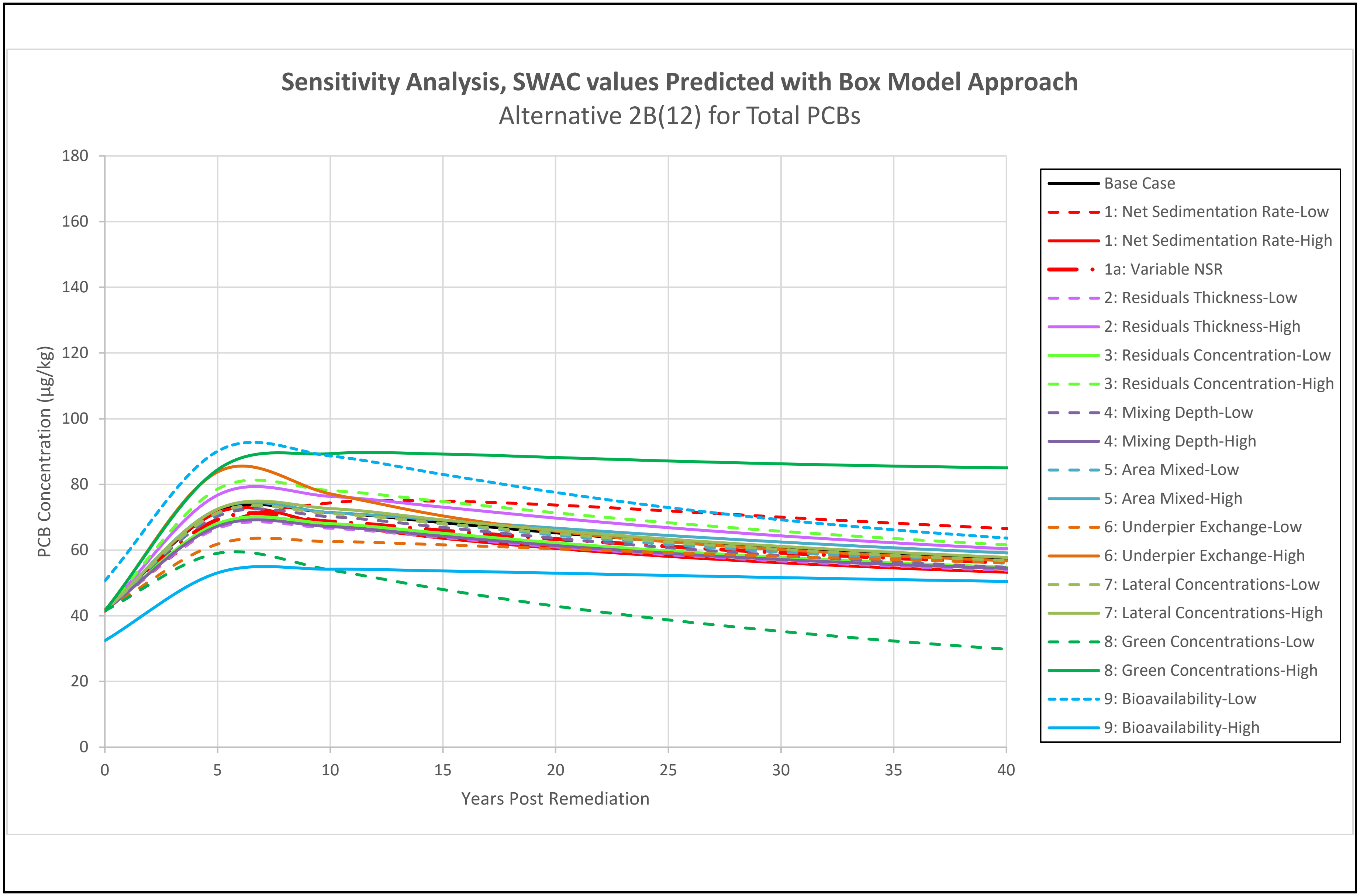


Figure 4a
Sensitivity Analysis, SWAC Values Predicted with Box Model Approach, Alternative 2B(12)
Feasibility Study - Appendix J
East Waterway Study Area

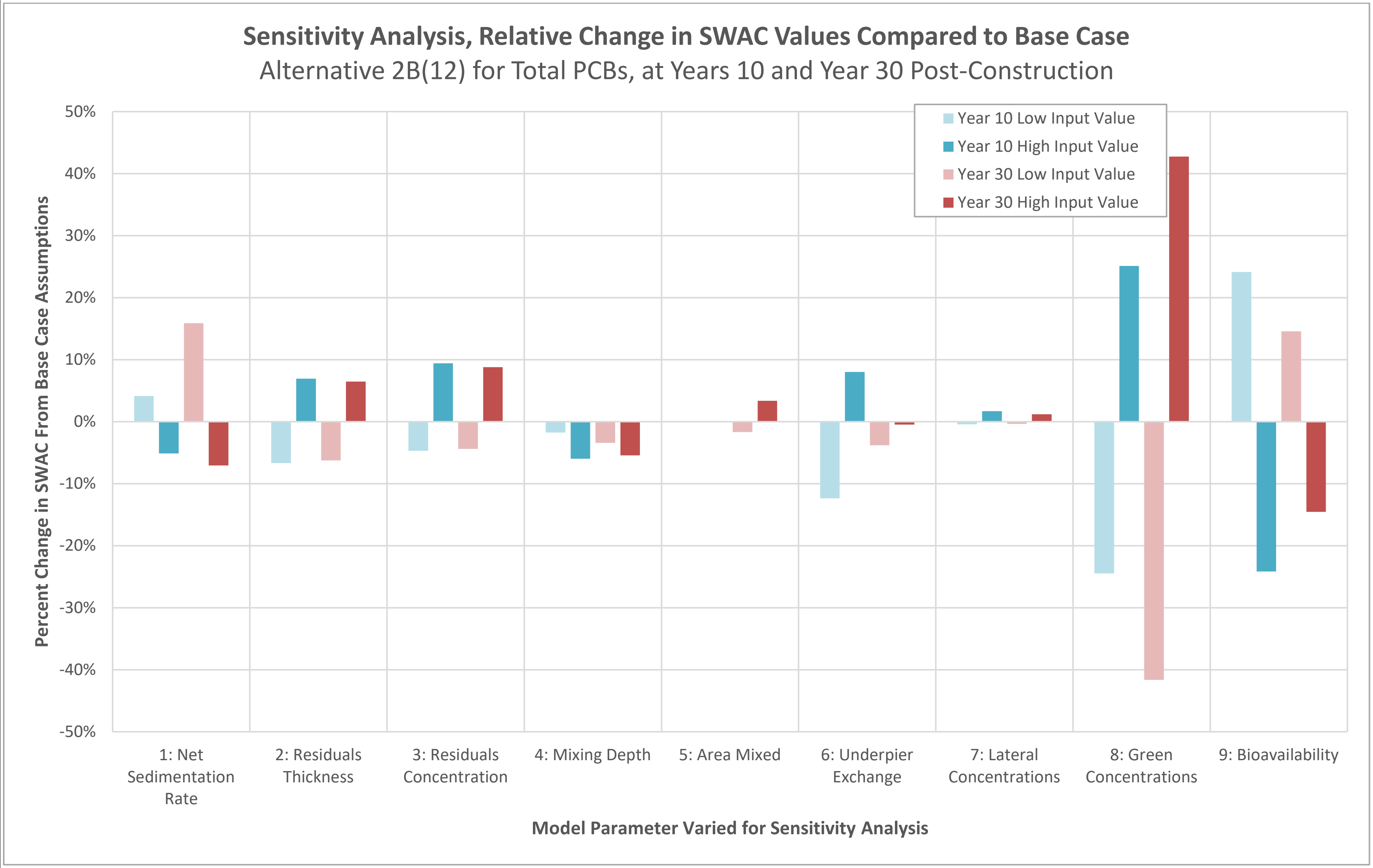


Figure 4b
Sensitivity Analysis, Relative Change in SWAC Values Compared to Base Case, Alternative 2B(12)
Feasibility Study - Appendix J
East Waterway Study Area

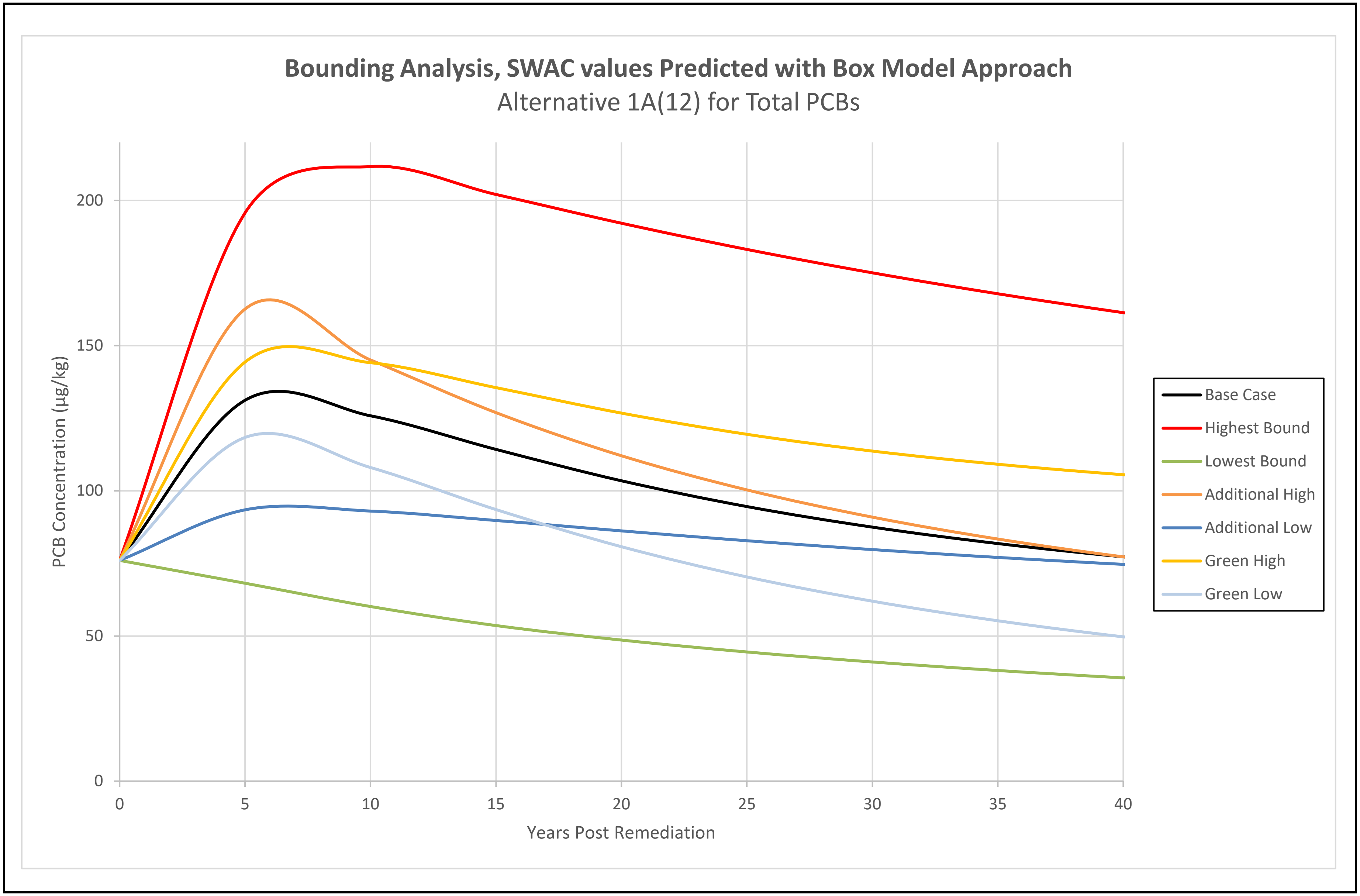


Figure 5a
Bounding Analysis, SWAC Values Predicted with Box Model Approach, Alternative 1A(12)
Feasibility Study - Appendix J
East Waterway Study Area

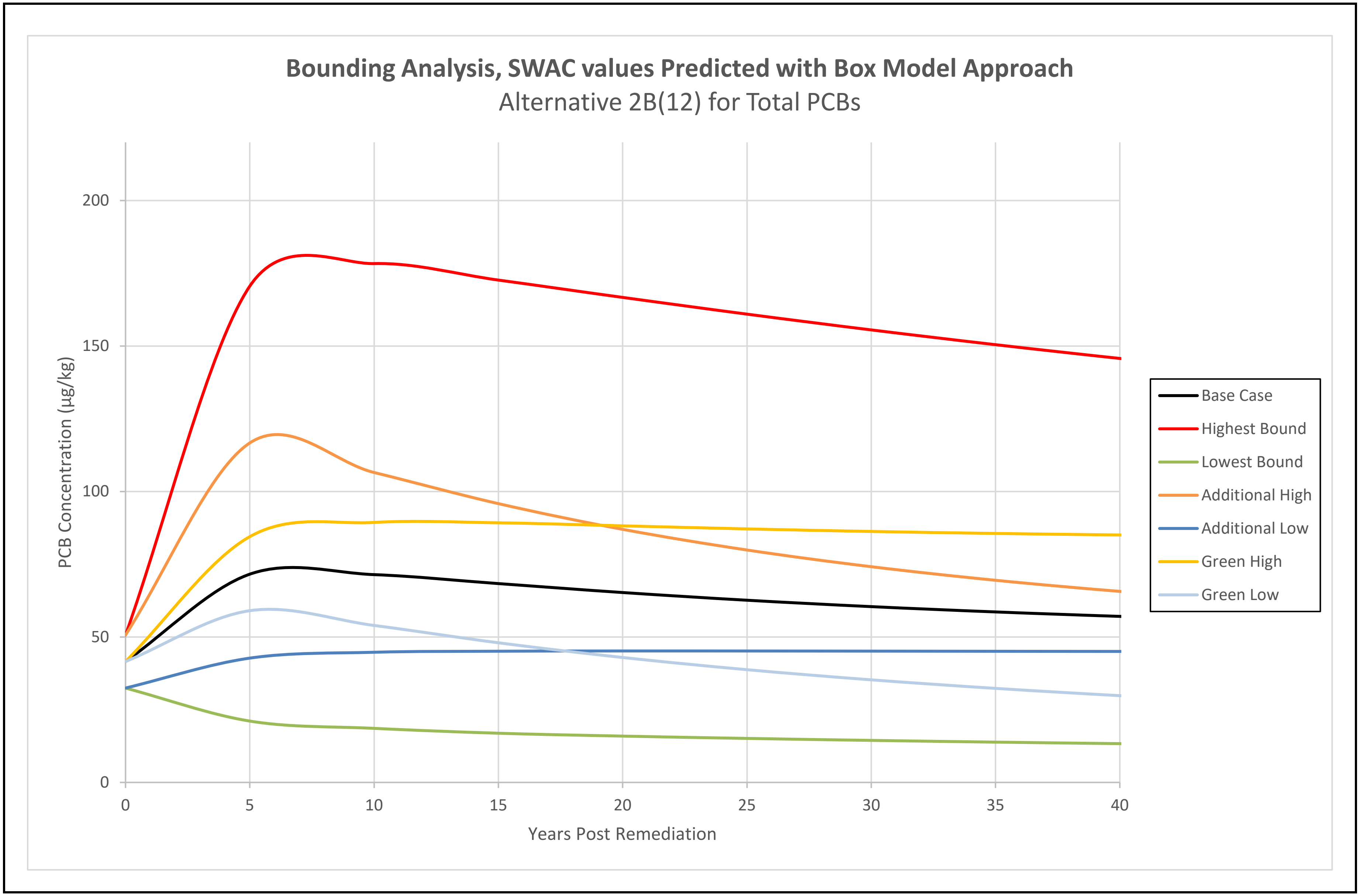


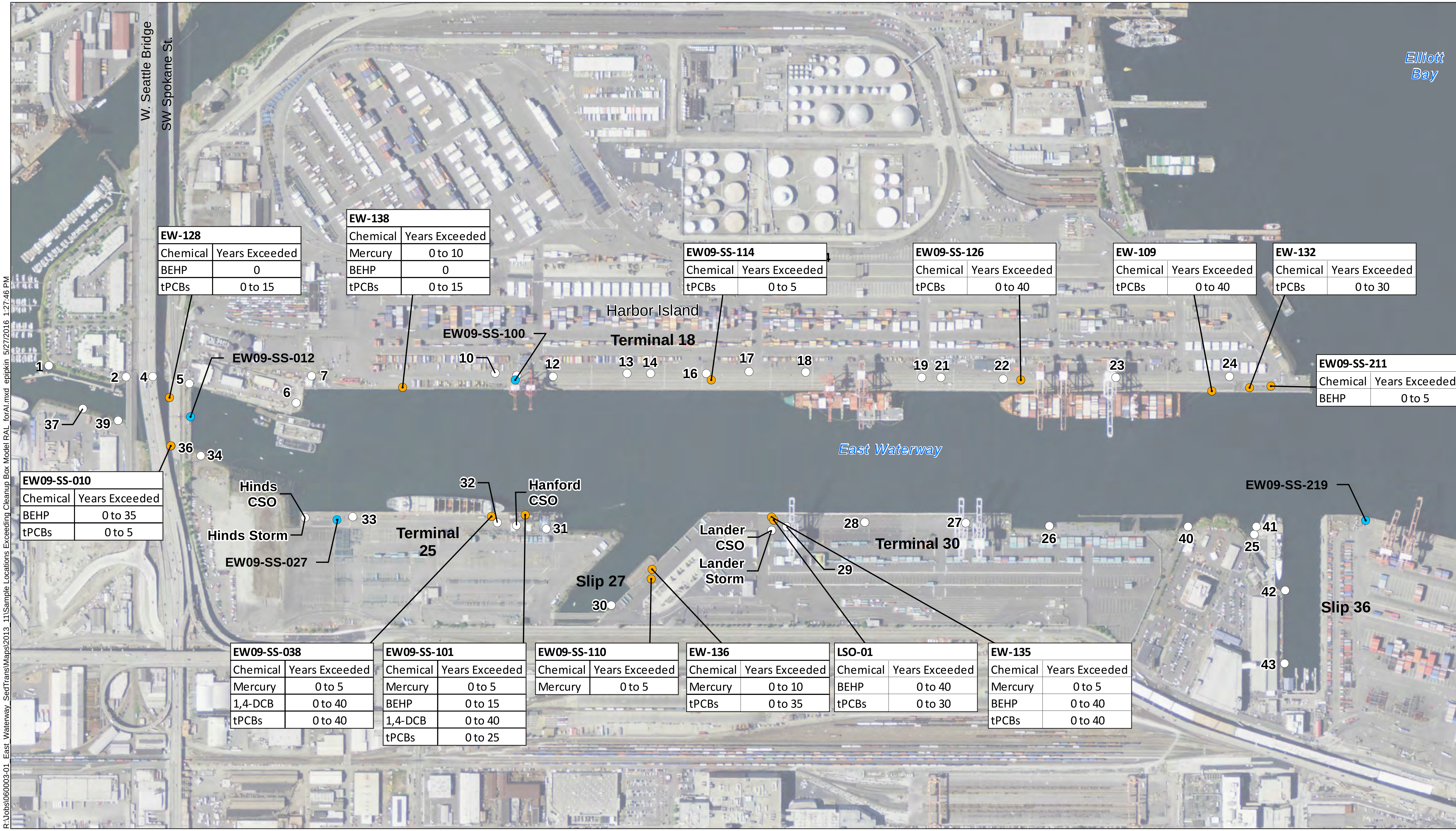
Figure 5b
Bounding Analysis, SWAC Values Predicted with Box Model Approach, Alternative 2B(12)
Feasibility Study - Appendix J
East Waterway Study Area

R:\Jobs\060003-01_East_Waterway_SedTrans\Maps\2013_12\Point Mixing Model Sample Locations.mxd dhanson 1/3/2014 12:34:56 PM

NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.

- Point Mixing Model Sample Location
- Outfall Locations (within PTM Model)

Figure 6
Point Mixing Model Sample Locations
Feasibility Study - Appendix J
East Waterway Study Area

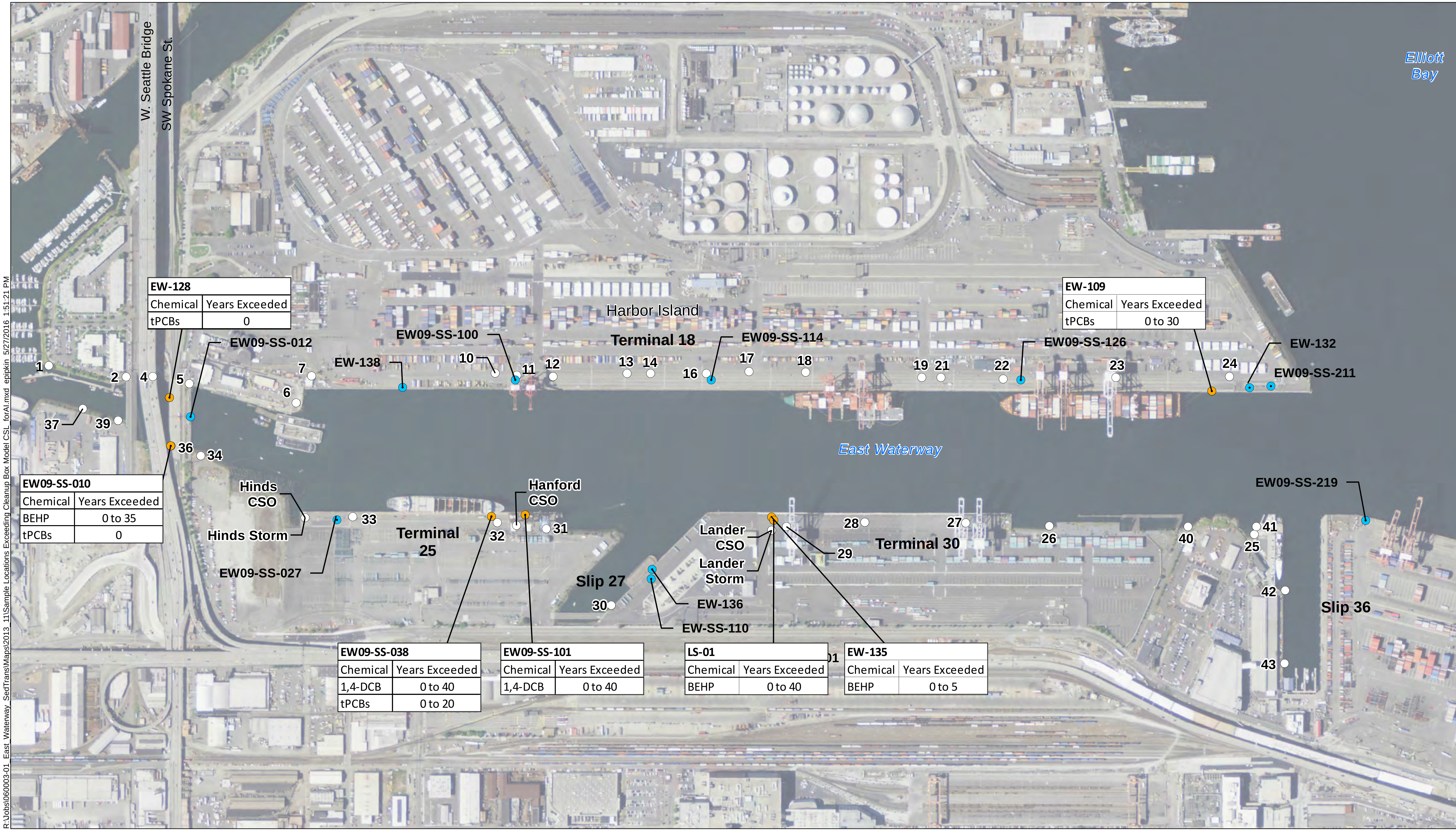


NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.
3. Only COCs predicted to exceed the RAL are shown; other COCs that are not predicted to exceed the RAL are not shown.

Sample Location
Sample Location with RAL Exceedance
Outfall Locations (within PTM Model)

0 500 1,000
Scale in Feet

Figure 7a
Point Mixing Model Results, Benthic RAL Exceedances
Feasibility Study - Appendix J
East Waterway Study Area



NOTES:

1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.
3. Only COCs predicted to exceed the CSL are shown; other COCs that are not predicted to exceed the CSL are not shown.

- Sample Location
- Sample Location with CSL Exceedance
- Outfall Locations (within PTM Model)

Figure 7b
Point Mixing Model Results, Benthic CSL Exceedances
Feasibility Study - Appendix J
East Waterway Study Area

NOTES:

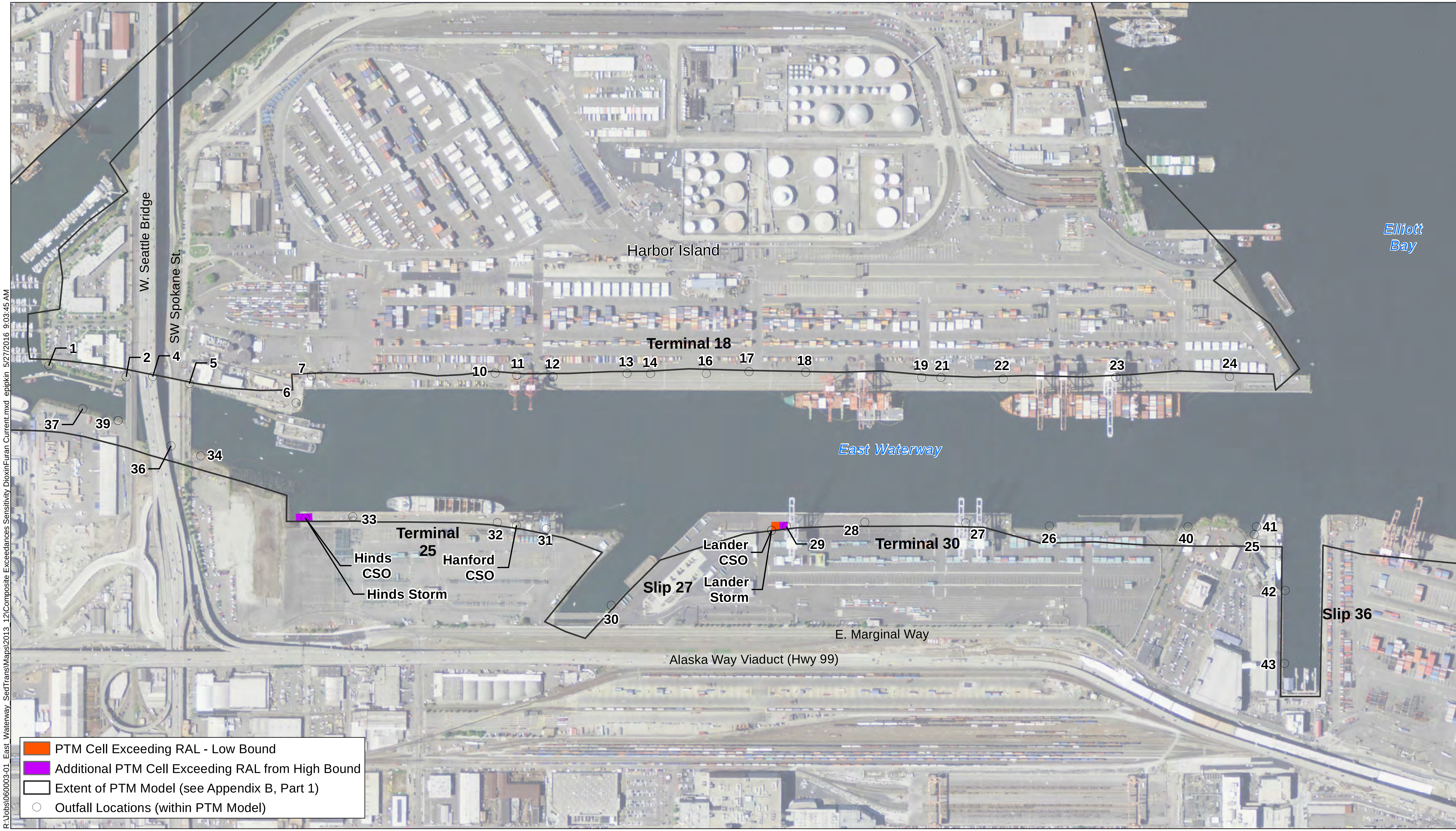
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.
3. tPCB SQS is 12 mg/kg-OC.
4. RAL is equal to SQS.
5. No Exceedences for Low Bound Simulation.

Figure 8a
Grid Model Bounding Analysis, tPCB Years 0 to 10
Feasibility Study - Appendix J
East Waterway Study Area

NOTES:

1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.
3. tPCB SQS is 12 mg/kg-OC.
4. RAL is equal to SQS.
5. No Exceedences for Low Bound Simulation.

Figure 8b
Grid Model Bounding Analysis, tPCB Years 11 to 30
Feasibility Study - Appendix J
East Waterway Study Area



NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.
3. Dioxin/Furan RAL is 25 ng TEQ/kg dw.

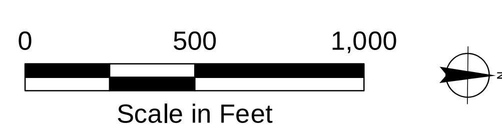
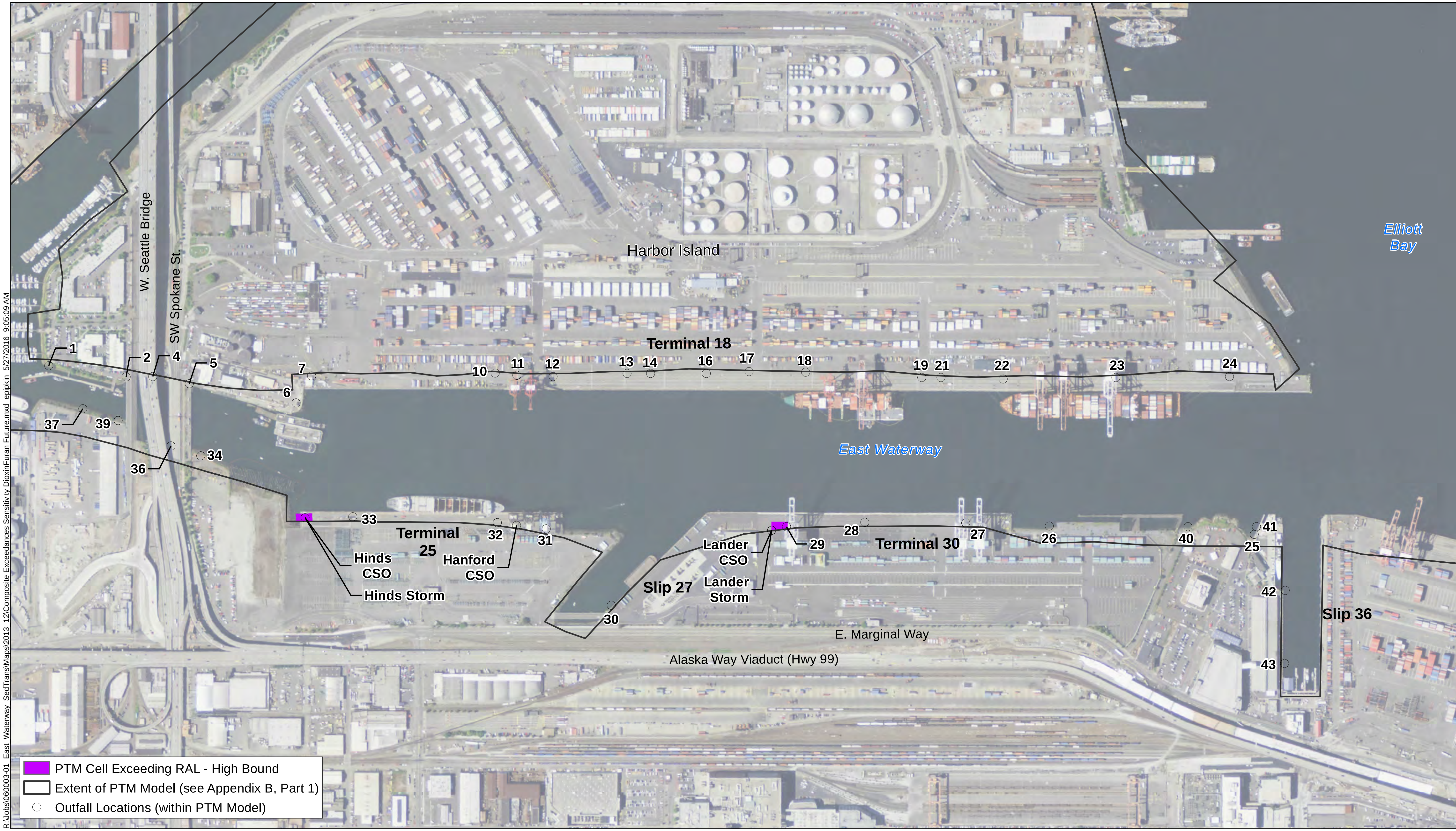


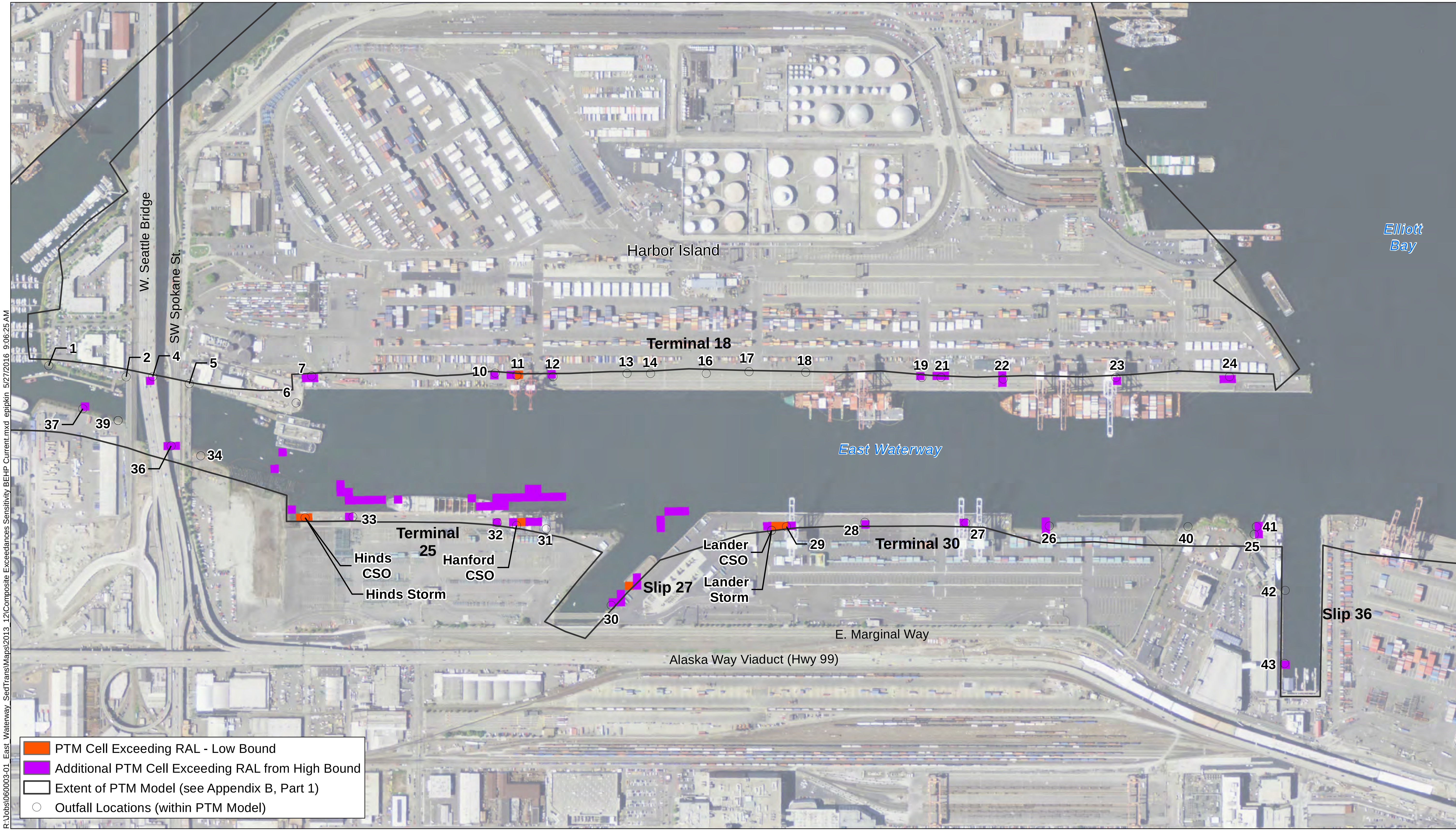
Figure 9a
Grid Model Bounding Analysis, Dioxin/Furan Years 0 to 10
Feasibility Study - Appendix J
East Waterway Study Area



NOTES:

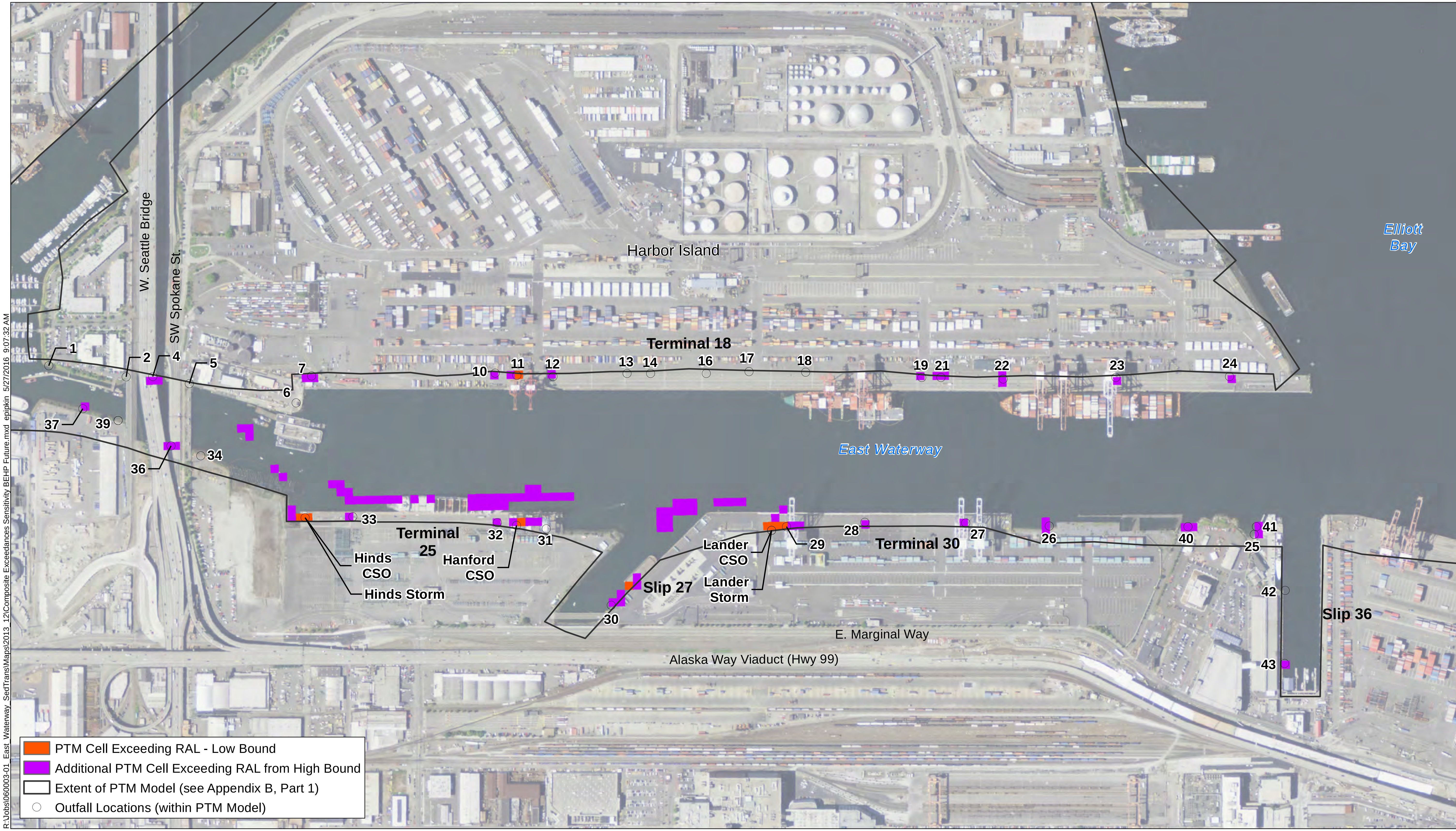
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.
3. Dioxin/Furan RAL is 25 ng TEQ/kg dw.
4. No Exceedences for Low Bound Simulation.

Figure 9b
Grid Model Bounding Analysis, Dioxin/Furan Years 11 to 30
Feasibility Study - Appendix J
East Waterway Study Area



NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.
3. BEHP SQS is 47 mg/kg-OC.
4. RAL is equal to SQS.

Figure 10a
Grid Model Bounding Analysis, BEHP Years 0 to 10
Feasibility Study - Appendix J
East Waterway Study Area



NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.
3. BEHP SQS is 47 mg/kg-OC.
4. RAL is equal to SQS

Figure 10b
Grid Model Bounding Analysis, BEHP Years 11 to 30
Feasibility Study - Appendix J
East Waterway Study Area

APPENDIX K – DIRECT ATMOSPHERIC DEPOSITION EVALUATION

EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

Prepared for

Port of Seattle

Prepared by

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Seattle, Washington 98101

June 2019

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1 DIRECT ATMOSPHERIC DEPOSITION EVALUATION

Direct atmospheric deposition is a pathway for chemicals to deposit directly on the water surface of the East Waterway (EW). Atmospheric deposition can occur through wet deposition, dry deposition, or gaseous exchange across the air/water interface. This appendix compares estimated flux-based annual mass to the EW of select risk driver chemicals from direct atmospheric deposition and direct discharge pathways.

Direct atmospheric deposition consists of the settling of particles present in the atmosphere directly onto the water surface of EW. The direct discharge pathway consists of combined sewer overflows [CSOs] and storm drain [SD] discharges. This comparison provides an indication of the importance of the direct atmospheric pathway relative to direct discharge pathways. Note that material from the atmosphere also settles onto the CSO and SD drainage basins, and some portion of that material from the atmosphere is entrained into stormwater that discharges via CSOs and SDs.

To determine the relative importance of the direct atmospheric deposition, flux-based estimates were calculated for the pathways as described in Section 2. This evaluation compares the flux-based estimates and does not consider the following:

- What proportion, if any, of the material associated with the direct atmospheric deposition to the surface of the EW or direct discharges is retained in the bedded sediments of the EW (i.e., mass transfer through the EW water column to sediments).
- Indirect atmospheric deposition of material on the CSO and SD drainage areas, which are included as components of the direct discharge pathway.
- Duwamish/Green River sediment mass inputs, which are predicted to account for 98.4% to 99.05% of the total sediment mass input to that is deposited in the EW.
- Gas phase exchange of organic chemicals (from air to water or from water to air).

The source of atmospheric deposition flux rate estimates are the *Lower Duwamish Waterway Source Control: Bulk Atmospheric Deposition Study Draft Data Report* (2013 Report; King County 2013), and *Lower Duwamish Waterway Source Control Project: Passive Atmospheric Deposition Sampling, Lower Duwamish Waterway: Monitoring Report - October 2005 to April 2007* (2008 Report; King County 2008). These reports provide estimates of passive bulk deposition, which is primarily an estimate of wet and dry deposition. The direct discharge annual masses were calculated to be consistent with the current CSO and SD chemistry assumptions developed for the EW Feasibility Study (FS) presented in Table 5-6 of the FS and the total suspended solids mass presented in the Sediment Transport Evaluation Report (Anchor QEA and Coast & Harbor Engineering 2012) (see Appendix B of the FS for more details).

2 EVALUATION METHOD

Estimated annual inputs for the direct atmospheric deposition pathway and the direct discharge pathway were calculated as described below. The mean atmospheric deposition and direct discharge base case mass are presented in the Figures 1 through 6, with the range bars indicating measures of uncertainty in those estimates based on the datasets. The calculated masses were then compared to determine the relative importance of the direct atmospheric deposition.

Atmospheric flux data collected by King County in the vicinity of the EW was converted to an annual mass deposition rate (Table 1). The annual deposition mass rate was estimated by multiplying the total open-water area of the EW (134 acres, or 542,278 square meters [m^2]) by the bulk atmospheric flux data reported by King County in both the 2013 Report and 2008 Report. To provide a range of estimated flux-based annual mass (milligrams per year [mg/year]), the mean, 25th percentile, and 75th percentile of the bulk atmospheric flux data were used in the following equation (Table 1):

Open-water area of the EW (m^2) x bulk flux rate (µg/m^2-day) x (1 mg/1,000 µg) x 365 days/year

The 2013 Report included the bulk atmospheric flux data for dioxin/furans, arsenic, mercury, high-molecular-weight polycyclic aromatic hydrocarbons (HPAHs), and polychlorinated biphenyls (PCBs), and the 2008 Report included the bis(2-ethylhexyl)phthalate (BEHP), HPAH, and PCB data. The flux data from the 2013 Report was used to estimate atmospheric deposition inputs to the EW because the newer data are of better quality due to improvements in the analytical techniques used during the 2008 study. Only the BEHP flux data from the 2008 Report were used because BEHP was not analyzed in the newer study. Bulk atmospheric flux data was compiled from two sampling stations: Beacon Hill (representing urban residential neighborhoods) and Duwamish (representing industrial areas; Figure 7). These stations are the most representative of direct atmospheric deposition to the EW surface based on proximity to the EW.

Direct discharge annual mass contributions from the CSO and SD inputs was calculated by multiplying either the low bounding (median), base case (mean), and high bounding (90th percentile) lateral chemistry data from the CSOs and SDs by their respective annual low bounding (25th percentile), base case (mean), and high bounding (75th percentile) total suspended solids data using the following equation (Table 2):

Concentration (mg/kg) x mean sediment load (kg/year)

The base case, low bounding, and high bounding masses are the same chemistry values used for the direct discharge inputs to the EW particle tracking model (see Table 5-6 of the FS).

3 EVALUATION RESULTS

Estimated chemical masses from the atmospheric deposition pathway are compared to the inputs from the direct discharge pathway and presented in Table 3 and Figures 1 through 6. Overall, the direct atmospheric deposition pathway contributes less chemical mass to the EW than the direct discharge pathway. Where atmospheric deposition masses are within or close to the range of the direct discharge mass, they may be of significance to sediment recontamination potential in the EW.

The mean, 25th, and 75th percentile bounding estimates of direct atmospheric masses to the EW water surface for arsenic, HPAH, mercury, and total PCBs are all lower than the low bounding estimate of the direct discharge masses (Table 3). Based on this evaluation, the atmospheric deposition pathway is not as significant for these parameters as the direct discharge pathway[1]. The determination of relative importance for these parameters is consistent with recent studies conducted by the Washington State Department of Ecology (Ecology) for the Lower Duwamish Waterway (LDW; Leidos and NewFields 2013).

For dioxin/furans at the Beacon Hill station, the 75th percentile direct atmospheric deposition estimate was just below (i.e., 0.04 mg/year) the low bounding estimate for the direct discharge pathway (Table 3 and Figure 6). There is less certainty regarding the range of direct discharge masses due to the source tracing dioxin/furan dataset being relatively small compared to the other contaminants. With this in mind, the small difference between the low bounding direct discharge and 75th percentile direct atmospheric deposition estimates could indicate that the direct atmospheric deposition pathway may be significant for dioxin/furan.

In contrast, at the Duwamish station, the 75th percentile bounding estimates of the direct atmospheric deposition masses for BEHP are greater than the base case estimate of the direct discharge mass (Table 3 and Figure 4). Also for BEHP direct atmospheric deposition mass, the 25th percentile and the base estimates at the Duwamish station and the 75th percentile

[1] The HPAH direct atmospheric deposition masses are biased low based on quality control issues in the analytical method for benzo(a)pyrene (see King County 2013 report for more details); therefore, HPAHs could have higher mass input for direct atmospheric deposition pathway.

estimate at the Beacon Hill station are greater than low bounding estimates of the direct discharge mass (Table 3 and Figure 4). Therefore, the direct atmospheric deposition pathway may be significant for BEHP. BEHP results and the evaluation limitations and uncertainties are further detailed below.

The LDW study also concluded that BEHP results were more variable based on location than for other chemicals (Leidos and NewFields 2013). Some of this variability could be due, in part, to the laboratory blank issues typical with BEHP analyses. BEHP was of greatest importance for potential mass contribution from direct atmospheric deposition to the LDW in the Ecology study (Leidos and NewFields 2013).

This evaluation is based on available information and is subject to the following limitations and uncertainties:

- No evaluation was conducted to determine what, if any, of either pathway masses are retained in the EW. The direct discharge recontamination potential is discussed in Section 9 of the FS. The evaluation likely overestimates the significance of the direct deposition mass because atmospheric contaminants typically consist of fine particulate matter with low settling rates through the water column. There are relatively few coarse particles compared to fine particles in the atmosphere, but coarse particles make up most of the mass of atmospheric particulate matter (Leidos and NewFields 2013). However, fine particles have more surface area than the coarse particles, so most chemicals are bound to the fine particulates. Therefore, it is likely that at least some of the direct fine particles, and the chemical mass, deposited in the EW will exit the site. This is consistent with the findings of the particle tracking model results for EW lateral particle inputs (Anchor QEA and Coast & Harbor Engineering 2012; Section 7.3.5).
- Gas-phase transfer rates were not evaluated. Gas-phase transfer can account for either a gain or loss of contaminants from the water column. Gas exchange can potentially represent a larger pathway to the water surface than wet or dry deposition (Leidos and NewFields 2013). However, the passive bulk deposition sampling method used to calculate flux rates did not measure atmospheric contaminant concentrations. Therefore, the gas exchange pathway cannot be estimated without a high degree of uncertainty without additional study data.

- An unknown amount of the atmospheric contaminant masses originate from outside of the EW source control area.
- Indirect atmospheric deposition of contaminants onto the CSO or SD basins was not quantified. However, the quantitative evaluation of the direct discharge pathway addresses all inputs from the SD and CSO basins regardless of source, including atmospheric deposition.
- Information on seasonal[2] and annual variability in the atmospheric deposition data has not been quantified.
- Relatively small atmospheric deposition data sample size for some contaminants results in relatively high uncertainty in the annual estimates.

As stated above, the indirect atmospheric deposition onto the upland drainage basins also contributes to the direct discharge pathway, but the contribution of such atmospheric deposition to the total direct discharges was not estimated as part of this evaluation. A preliminary estimate of indirect atmospheric deposition conducted for the LDW indicated that indirect deposition could potentially be a significant contribution to the total direct discharge. However, the wide ranging indirect deposition estimates yielded results with a high degree of uncertainty, therefore producing a better estimate of indirect loadings was identified as a data gap for the LDW (Leidos and NewFields 2013).

Most of the contribution from atmospheric deposition is likely captured in the direct discharge pathways inputs. Direct atmospheric deposition to the EW surface does not appear to be a significant pathway for most contaminants to the EW. However, the small difference between the low bounding direct discharge and 75th percentile direct atmospheric deposition estimates could indicate that the direct atmospheric deposition pathway may be significant for dioxin/furan and BEHP. Due to uncertainties in estimates and methods to evaluate the entire pathway to the sediment, direct atmospheric deposition quantitative estimates were not included in modeling for recontamination potential or future average site-wide surface sediment concentrations.

[2] Except for metals and PAHs, which were evaluated over all seasons over approximately a 1-year period.

4 REFERENCES

Anchor QEA and Coast & Harbor Engineering, 2012. Final Sediment Transport Evaluation Report (STER), East Waterway Operable Unit Supplemental Remedial Investigation/ Feasibility Study. Prepared for Port of Seattle. August.

King County, 2008. Lower Duwamish Waterway Source Control Project: Passive Atmospheric Deposition Sampling, Lower Duwamish Waterway: Monitoring report - October 2005 to April 2007. King County Department of Natural Resources and Parks, Seattle, WA.

King County, 2013. Lower Duwamish Waterway Source Control: Bulk Atmospheric Deposition Study Draft Data Report. King County Department of Natural Resources and Parks, Seattle, WA.

Leidos and NewFields, 2013. Lower Duwamish Waterway Air Deposition Scoping Study Data Gaps Report. Prepared for Washington State Department of Ecology, Toxics Cleanup Program. December.

TABLES

Table 1
Direct Atmospheric Deposition Pathway Flux Rates and Annual Mass Rates

Inputs	Arsenic		Mercury		Total HPAHs		BEHP		Total PCBs		Dioxin/Furan TEQ	
	Flux Rate[1] (µg/m^2-day)	Annual Mass to the EW[2] (mg/yr)	Flux Rate[1] (µg/m^2-day)	Annual Mass to the EW[2] (mg/yr)	Flux Rate[1] (µg/m^2-day)	Annual Mass to the EW[2] (mg/yr)	Flux Rate[1] (µg/m^2-day)	Annual Mass to the EW[2] (mg/yr)	Flux Rate[1] (µg/m^2-day)	Annual Mass to the EW[2] (mg/yr)	Flux Rate[1] (µg/m^2-day)	Annual Mass to the EW[2] (mg/yr)
Duwamish Station												
mean	1.1	217,723	0.023	4,552	0.73	144,489	4.7	928,490	0.012	2,395	0.0000050	0.980
25th percentile	0.71	141,322	0.0077	1,526	0.45	89,069	1.8	353,107	0.0051	1,005	0.0000027	0.53
75th percentile	1.4	274,529	0.025	4,968	0.85	168,439	6.5	1,291,692	0.021	4,216	0.0000078	1.55
Beacon Hill Station												
mean	0.38	75,213	0.011	2,177	0.28	55,420	1.6	324,605	0.0044	867	0.0000072	1.43
25th percentile	0.25	48,493	0.0061	1,215	0.12	23,554	1.2	227,818	0.0023	463	0.0000049	0.96
75th percentile	0.50	99,361	0.015	2,969	0.34	66,505	2.0	394,475	0.0054	1,078	0.0000097	1.91

Notes:

1. Flux rates from King County (2013) report.
2. Annual mass calculated by multiplying flux rate by the East Waterway open-water surface area (134 acres or 542,278 square meters).
3. Flux rates from King County (2008) report.

EW – East Waterway

µg/m^2-day – microgram per square meter-day

BEHP – bis(2-ethylhexyl)phthalate

HPAH – high-molecular-weight polycyclic aromatic hydrocarbon

mg/yr – milligram per year

PCB – polychlorinated biphenyl

TEQ – toxic equivalent

Table 2
Direct Discharge Pathway Chemistry and Annual Mass Rates

Inputs	Arsenic		Mercury		Total HPAHs		BEHP		Total PCBs		Dioxin/Furan TEQ	
	Chemistry (mg/kg dw)[1]	Annual Mass to the EW[2] (mg/yr)	Chemistry (mg/kg dw)[1]	Annual Mass to the EW[2] (mg/yr)	Chemistry (mg/kg dw)[1]	Annual Mass to the EW[2] (mg/yr)	Chemistry (mg/kg dw)[1]	Annual Mass to the EW[2] (mg/yr)	Chemistry (mg/kg dw)[1]	Annual Mass to the EW[2] (mg/yr)	Chemistry (mg/kg dw)[1]	Annual Mass to the EW[2] (mg/yr)
Hinds CSO												
Base Case[3]	5	1,628	1.71	557	4,000	1,302	6,700	2,181	260	85	16	0.0052
Low Bounding[4]	6	1,483	0.36	89	2,900	717	3,000	742	240	59	7.6	0.0019
High Bounding[5]	9	3,612	2.57	1031	10,000	4,013	23,000	9,230	630	253	37	0.015
Lander CSO												
Base Case[3]	2	25,800	0.21	2709	1,800	23,220	1,000	12,900	11	142	1.8	0.023
Low Bounding[4]	2	19,676	0.25	2460	2,200	21,644	800	7,870	11	108	1.8	0.018
High Bounding[5]	2	31,940	0.26	4152	2,700	43,119	1,700	27,149	18	287	2.6	0.042
Hanford #2 CSO												
Base Case[3]	6	145,140	2.00	48331	3,900	94,341	7,700	186,263	270	6,531	30	0.73
Low Bounding[4]	6	110,220	0.72	13226	3,100	56,947	3,300	60,621	250	4,593	30	0.55
High Bounding[5]	9	268,290	2.94	87641	6,200	184,822	27,000	804,870	510	15,203	44	1.3
Total CSO												
Base Case[3]	--	172,568	--	51,596	--	118,863	--	201,344	--	6,758	--	0.75
Low Bounding[4]	--	131,379	--	15,775	--	79,307	--	69,233	--	4,760	--	0.57
High Bounding[5]	--	303,842	--	92,825	--	231,954	--	841,249	--	15,743	--	1.37
Nearshore SDs[4]												
Base Case[3]	10	367,630	0.09	3,309	5,500	202,197	8,300	305,133	160	5,882	15	0.55
Low Bounding[4]	10	171,350	0.08	1,371	4,400	75,394	6,200	106,237	39	668	7.9	0.14
High Bounding[5]	15	712,500	0.14	6,650	14,000	665,000	19,000	902,500	440	20,900	32	1.52
S Lander St SD												
Base Case[3]	9	287,460	0.15	4,791	14,000	447,160	12,000	383,280	120	3,513	68	2.17
Low Bounding[4]	10	150,700	0.13	1,959	5,500	82,885	9,300	140,151	53	799	68	1.02
High Bounding[5]	20	845,600	0.29	12,261	17,000	718,760	21,000	887,880	280	11,838	93	3.93
All Non-nearshore SDs												
Base Case[3]	10	69,200	0.19	1,315	10,000	69,200	19,000	131,480	290	2,007	68	0.471
Low Bounding[4]	7	22,505	0.12	386	4,000	12,860	9,400	30,221	58	186	68	0.219
High Bounding[5]	20	204,600	0.32	3,274	11,000	112,530	24,000	245,520	460	4,706	93	0.951
Total SD												
Base Case[3]	--	724,290	--	9,414	--	718,557	--	819,893	--	11,402	--	3.2
Low Bounding[4]	--	344,555	--	3,716	--	171,139	--	276,609	--	1,653	--	1.4
High Bounding[5]	--	1,762,700	--	22,185	--	1,496,290	--	2,035,900	--	37,444	--	6.4
Total Direct Discharges (CSO + SD)												
Base Case[3]	--	**896,858**	--	**61,011**	--	**837,420**	--	**1,021,237**	--	**18,160**	--	**3.9**
Low Bounding[4]	--	**475,934**	--	**19,491**	--	**250,446**	--	**345,842**	--	**6,413**	--	**1.9**
High Bounding[5]	--	**2,066,542**	--	**115,010**	--	**1,728,244**	--	**2,877,149**	--	**53,188**	--	**7.8**

Table 2
Direct Discharge Pathway Chemistry and Annual Mass Rates

Notes:
1. Direct discharge chemistry values derived form source tracing dataset; see Table 5-6 of the Feasibility Study.
2. Annual mass calculated by multiplying annual average sediment load TSS Values (EW STER; Anchor QEA 2012) using the PTM approach, as follows:

50th Percentile:		25th Percentile:		75th Percentile:	
Hinds CSO =	326 kg	Hinds CSO =	247 kg	Hinds CSO =	401 kg
Lander CSO =	12,900 kg	Lander CSO =	9,838 kg	Lander CSO =	15,970 kg
Hanford #2 CSO =	24,190 kg	Hanford #2 CSO =	18,370 kg	Hanford #2 CSO =	29,810 kg
Nearshore SDs =	36,763 kg	Nearshore SDs =	17,135 kg	Nearshore SDs =	47,500 kg
S Lander St SD =	31,940 kg	S Lander St SD =	15,070 kg	S Lander St SD =	42,280 kg
Non-nearshore SDs =	6,920 kg	Non-nearshore SDs =	3,215 kg	Non-nearshore SDs =	10,230 kg

3. Mean chemistry values and 50th percentile TSS values are used for Base Case scenarios.
4. Median chemistry values and 25th percentile TSS values are used for Low Bounding case scenarios.
5. 90th percentile chemistry values and 75th percentile TSS values are used for High Bounding Case scenarios.

µg/kg dw – microgram per kilogram dry weight
BEHP – bis(2-ethylhexyl)phthalate
CSO – combined sewer overflow
EW – East Waterway
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
mg/yr – milligram per year
PCB – polychlorinated biphenyl
PTM – particle tracking model
SD – storm drain
TEQ – toxic equivalent
TSS – total suspended solids

Table 3
Direct Discharge and Direct Atmospheric Deposition Pathway Comparison

Inputs (mg/yr)	Direct Discharge Pathway	Direct Atmospheric Deposition Masses	
		Duwamish Station	Beacon Hill Station
Arsenic			
Base Case/mean	896,858	217,723	75,213
Low Bounding/25th percentile	475,934	141,322	48,493
High Bounding/75th percentile	2,066,542	274,529	99,361
Mercury			
Base Case/mean	61,011	4,552	2,177
Low Bounding/25th percentile	19,491	1,526	1,215
High Bounding/75th percentile	115,010	4,968	2,969
Total HPAHs			
Base Case/mean	837,420	144,489	55,420
Low Bounding/25th percentile	250,446	89,069	23,554
High Bounding/75th percentile	1,728,244	168,439	66,505
BEHP			
Base Case/mean	1,021,237	928,490	324,605
Low Bounding/25th percentile	345,842	353,107	227,818
High Bounding/75th percentile	2,877,149	1,291,692	394,475
Total PCBs			
Base Case/mean	18,160	2,395	867
Low Bounding/25th percentile	6,413	1,005	463
High Bounding/75th percentile	53,188	4,216	1,078
Dioxin/Furan TEQ			
Base Case/mean	3.95	0.98	1.43
Low Bounding/25th percentile	1.95	0.53	0.96
High Bounding/75th percentile	7.77	1.55	1.91

Notes:

Indicates direct atmospheric deposition mass is greater than Low Bounding but less than Base Case direct discharge masses

Indicates direct atmospheric deposition mass is greater than Base Case but less than High Bounding direct discharge masses

BEHP – bis(2-ethylhexyl)phthalate

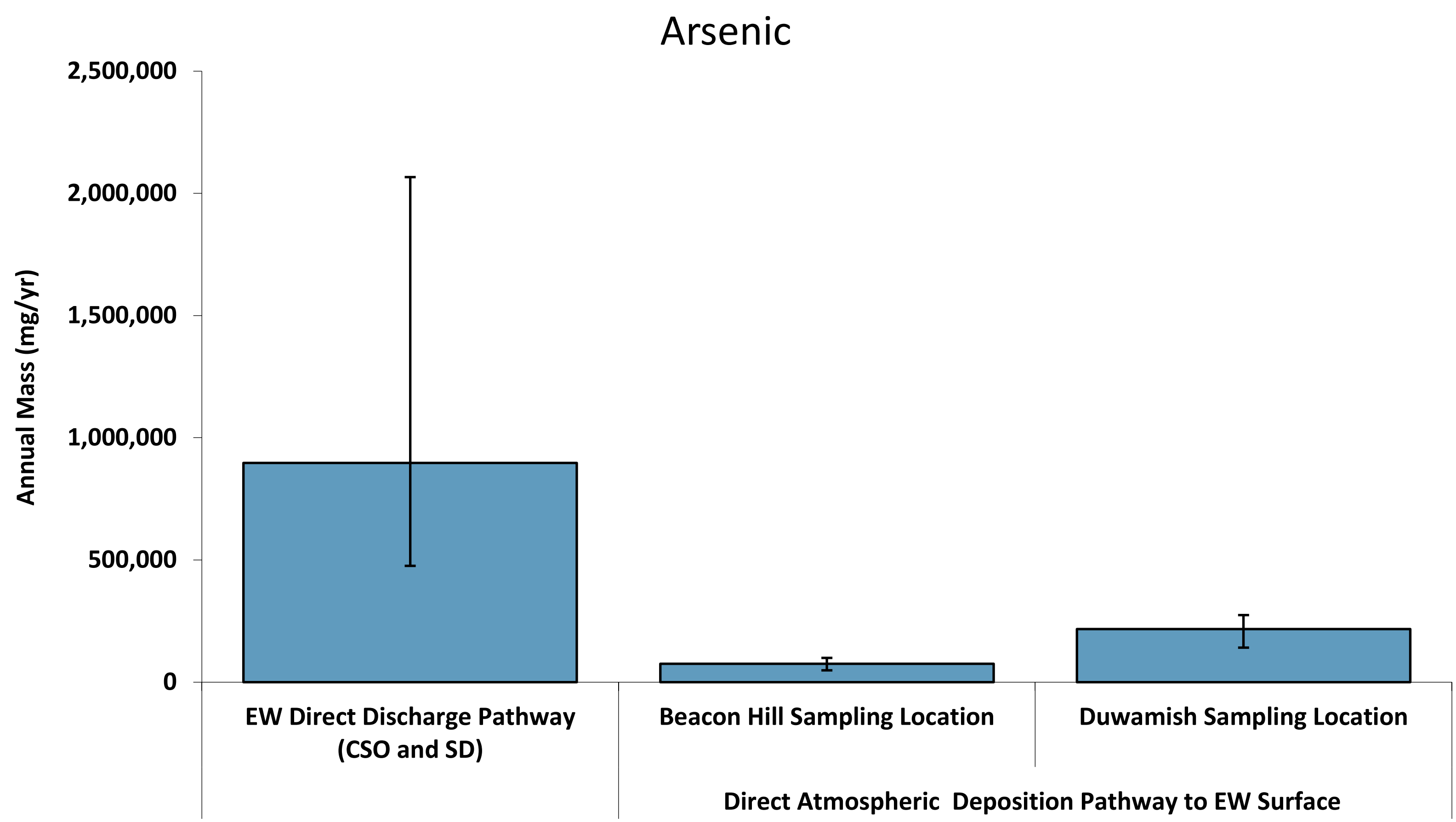
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon

mg/yr – milligram per year

PCB – polychlorinated biphenyl

TEQ – toxic equivalent

FIGURES



Notes:

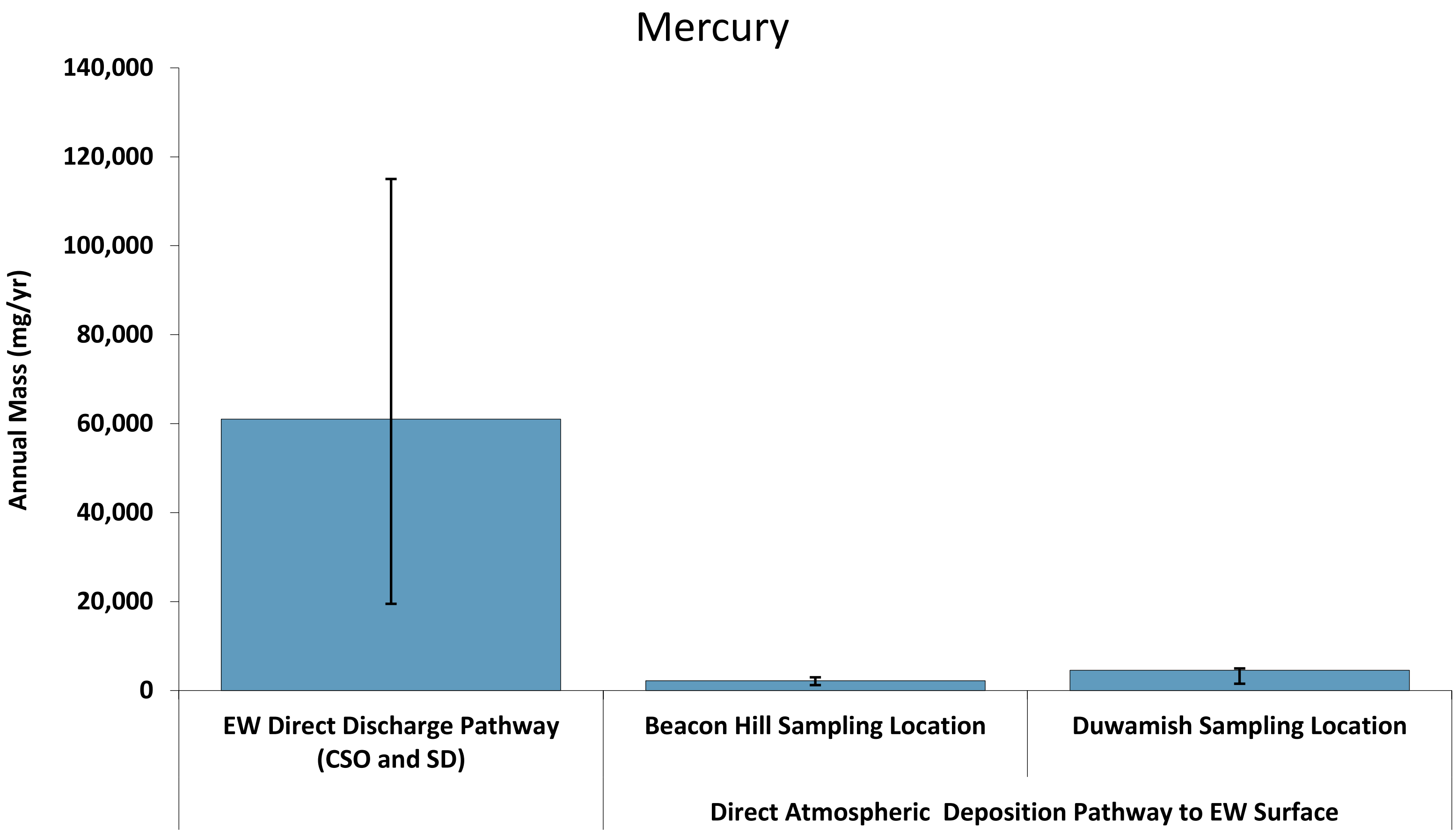
1. The blue bar is the base case/mean mass for both the direct discharge and direct atmospheric deposition. The range bar indicates 25th and 75th percentile mass for direct atmospheric deposition at each sampling station, or for direct discharge, the low bounding and the high bounding mass.

Figure 1

Relative Comparison of Arsenic Mass Based on Direct Discharge and Direct Atmospheric Deposition Pathways

Feasibility Study - Appendix K

East Waterway Study Area



Notes:

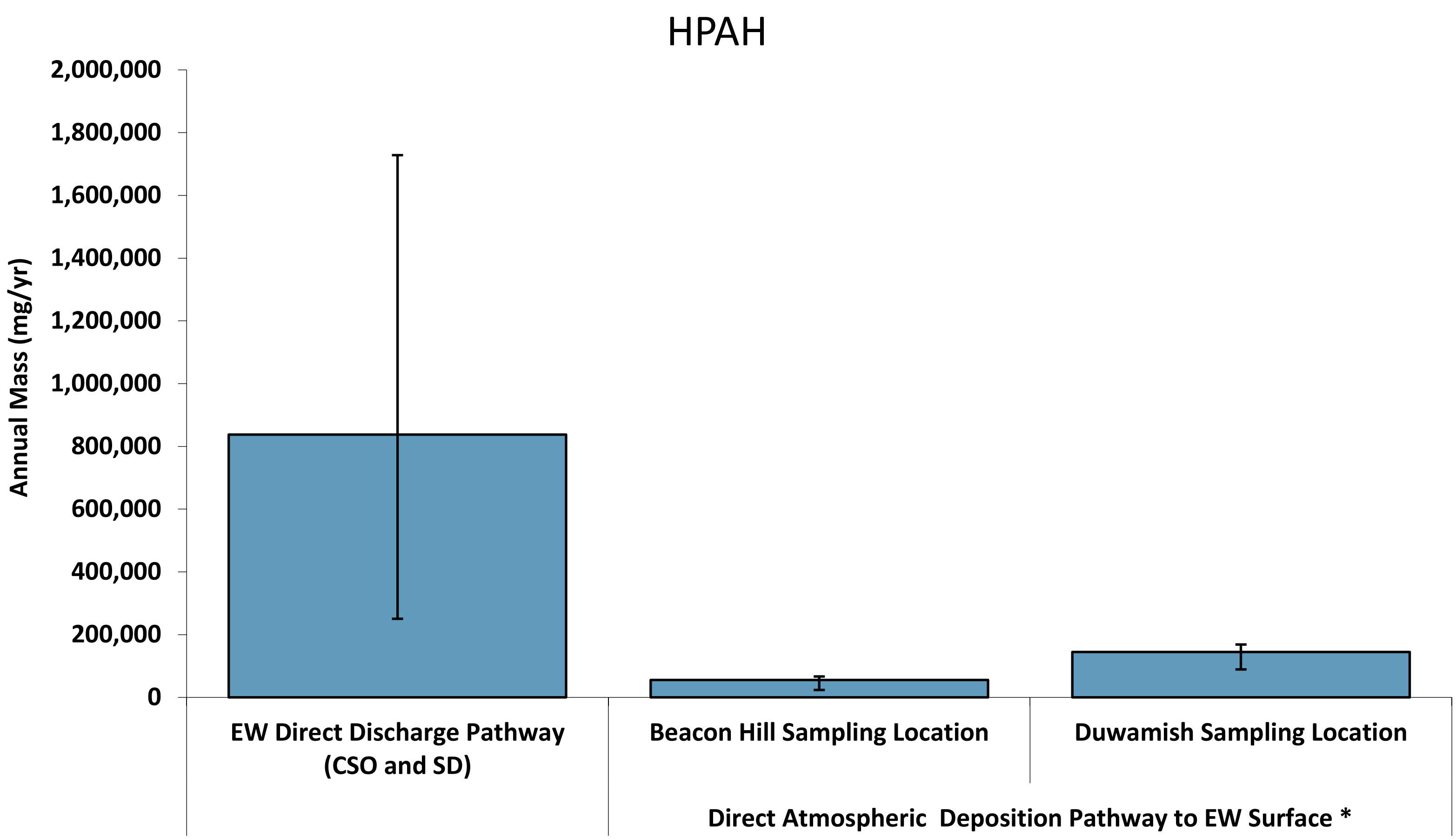
1. The blue bar is the base case/mean mass for both the direct discharge and direct atmospheric deposition. The range bar indicates 25th and 75th percentile mass for direct atmospheric deposition at each sampling station, or for direct discharge, the low bounding and the high bounding mass.

Figure 2

Relative Comparison of Mercury Mass Based on Direct Discharge and Direct Atmospheric Deposition Pathways

Feasibility Study - Appendix K

East Waterway Study Area



Notes:

* = The HPAH direct atmospheric deposition masses are biased low due to low laboratory recoveries for benzo(a)pyrene

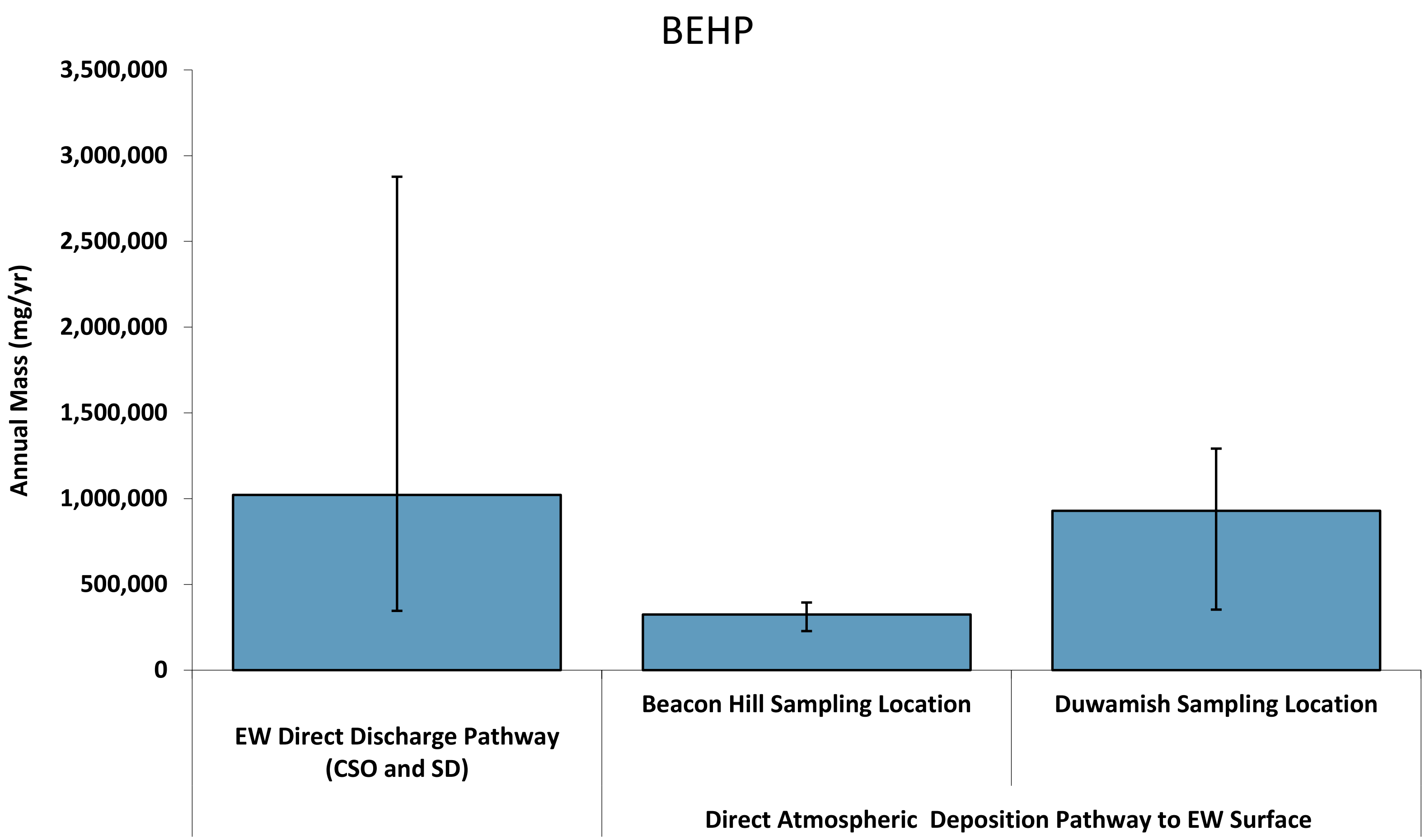
1. The blue bar is the base case/mean mass for both the direct discharge and direct atmospheric deposition. The range bar indicates 25th and 75th percentile mass for direct atmospheric deposition at each sampling station, or for direct discharge, the low bounding and the high bounding mass.

Figure 3

Relative Comparison of HPAH Mass Based on Direct Discharge and Direct Atmospheric Deposition Pathways

Feasibility Study - Appendix K

East Waterway Study Area

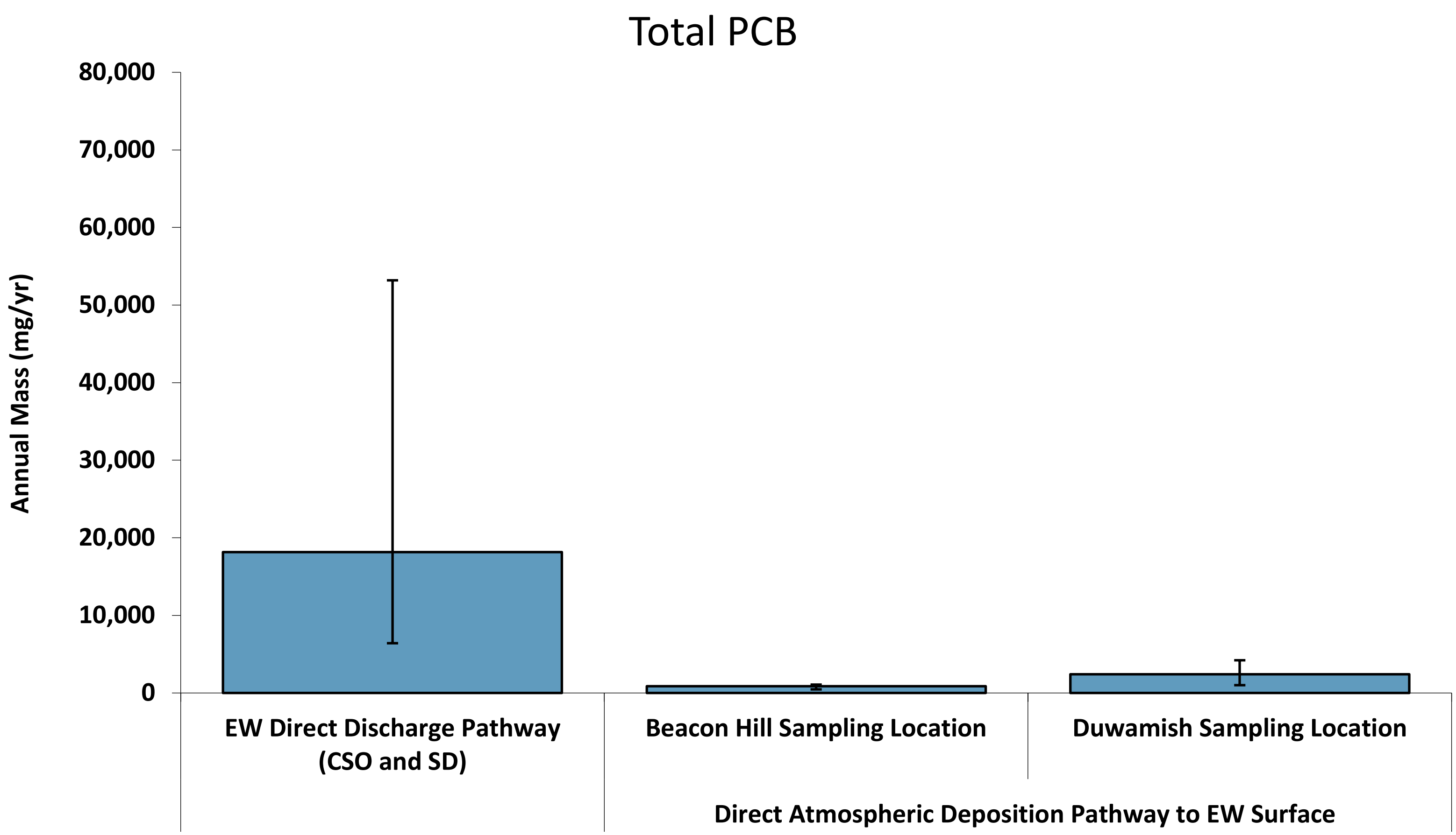


Notes:

1. The blue bar is the base case/mean mass for both the direct discharge and direct atmospheric deposition. The range bar indicates 25th and 75th percentile mass for direct atmospheric deposition at each sampling station, or for direct discharge, the low bounding and the high bounding mass.

Figure 4

Relative Comparison of BEHP Mass Based on Direct Discharge and Direct Atmospheric Deposition Pathways



Notes:

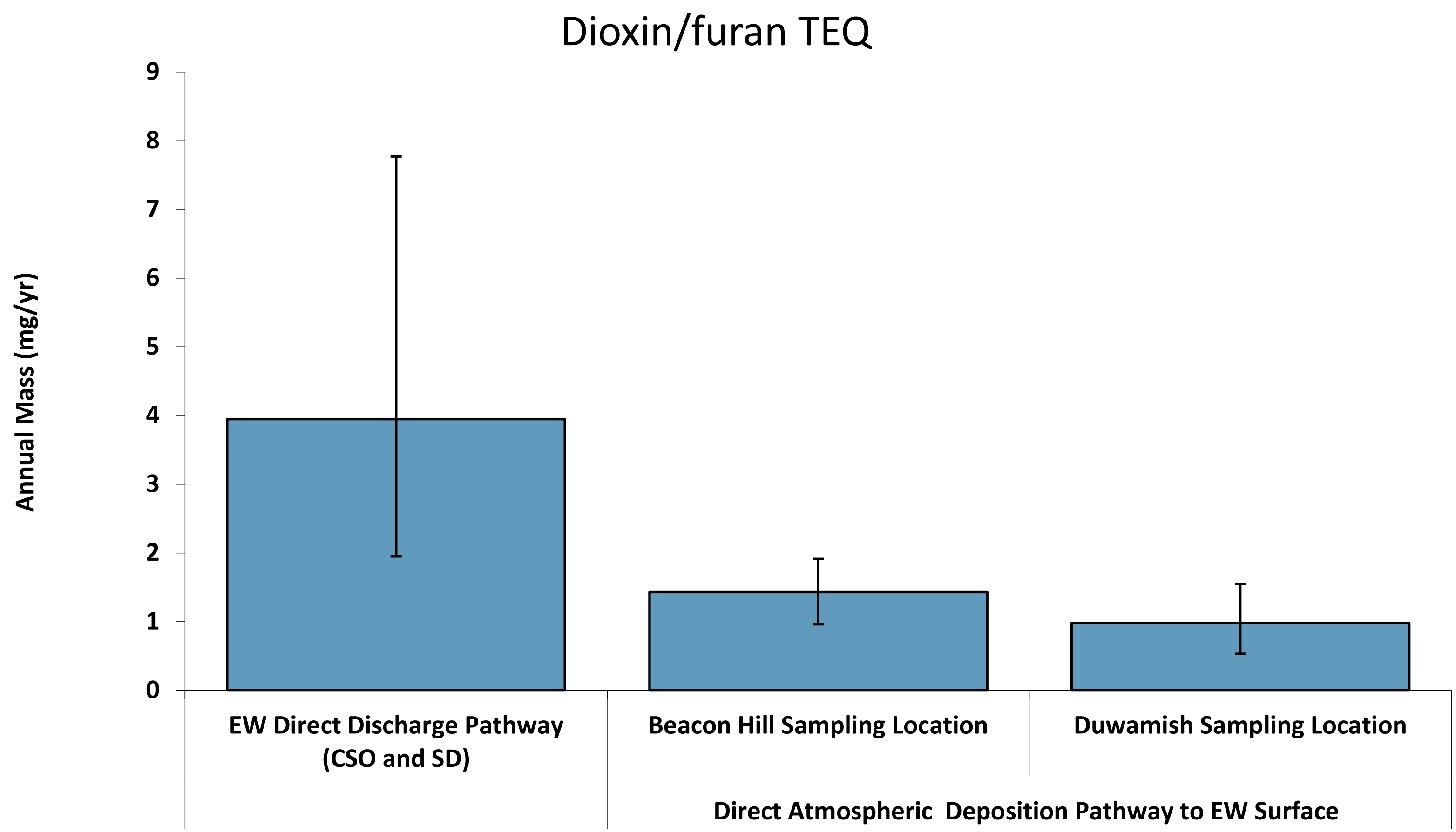
1. The blue bar is the base case/mean mass for both the direct discharge and direct atmospheric deposition. The range bar indicates 25th and 75th percentile mass for direct atmospheric deposition at each sampling station, or for direct discharge, the low bounding and the high bounding mass.

Figure 5

Relative Comparison of Total PCB Mass Based on Direct Discharge and Direct Atmospheric Deposition Pathways

Feasibility Study - Appendix K

East Waterway Study Area



Notes:

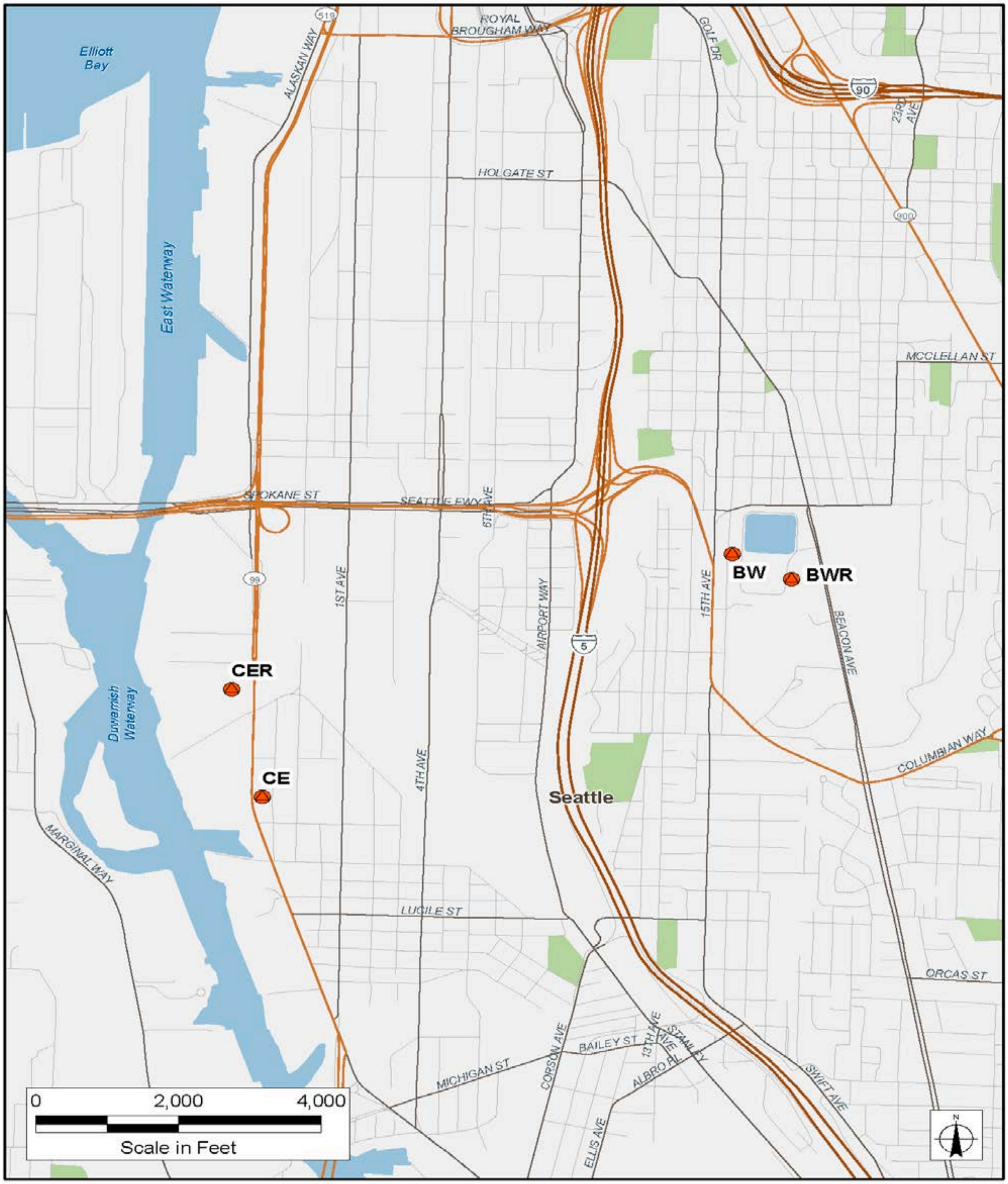
1. The blue bar is the base case/mean mass for both the direct discharge and direct atmospheric deposition. The range bar indicates 25th and 75th percentile mass for direct atmospheric deposition at each sampling station, or for direct discharge, the low bounding and the high bounding mass.

Figure 6

Relative Comparison of Dioxin/Furan TEQ Mass Based on Direct Discharge and Direct Atmospheric Deposition Pathways

Feasibility Study - Appendix K

East Waterway Study Area



Source: King County (2008)

Note: CE = Duwamish, CER = relocated Duwamish, BW = Beacon Hill, BWR = relocated Beacon Hill.
Data from the re-located stations were presented in the 2013 report, whereas data from both the original and relocated locations were used in the 2008 report.

Figure 7

Locations of Air Deposition Monitoring Stations from the King County LDW Study

Feasibility Study - Appendix K

East Waterway Study Area

APPENDIX L – ALTERNATIVES SCREENING

EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

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June 2019

TABLE OF CONTENTS

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1 INTRODUCTION

This appendix presents the focused screening of potential remedial alternatives for the East Waterway (EW) Operable Unit Feasibility Study (FS) in accordance with Environmental Protection Agency (EPA; 1988) Remedial Investigation/FS guidance. Screening of remedial technologies and alternatives was previously performed in the EPA-approved *Final Remedial Alternative and Disposal Site Screening Memorandum* (Screening Memo; Anchor QEA 2012) to meet requirements for alternatives screening under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This additional screening evaluation has been performed at the request of, and in coordination with, EPA to screen a wide array of potential alternatives to understand the influence of different cleanup components on effectiveness, implementability, and cost, to select a representative set of alternatives for detailed analysis in Sections 8, 9, and 10 of the FS. This appendix presents the information as follows:

- **Alternative Components** (Section 2) develops the logic for the matrix of alternatives.
- **Comparison of Alternatives** (Section 3) compares the alternatives for effectiveness, implementability, and cost.
- **Screening of Alternatives** (Section 4) presents the rationale and list of alternatives retained for detailed evaluation in the FS.

2 ALTERNATIVE COMPONENTS

Three components were varied to develop the remedial alternatives: the remedial action levels (RALs; also discussed in FS Section 6), the remedial technology assignments in the open-water areas, and the remedial technology assignments in limited access areas. The alternatives were generated by modifying these three components one at a time to understand the effect of each. The components and the resulting suite of alternatives are explained in the following sections.

2.1 Remedial Action Levels

RALs are the point-based concentrations above which sediment is remediated and are one of the components modified to produce the array of remedial alternatives. FS Table 6-2 and Section 6.2.2 present the RALs included in this screening. The RALs were developed in Section 6 to achieve outcomes relative to the site-specific remedial action objectives (RAOs). Key risk driver contaminants of concern (COCs) have the same RAL for all alternatives, with the exception of total polychlorinated biphenyls (PCBs), which has three different RALs. Because only the total PCBs RAL is varied among the alternatives, the RAL sets are denoted by each total PCB RAL. The three sets of screening RALs are shown in Table 2-1.

Table 2-1
Remedial Action Levels for Technology Development

RAL Set Denotation	Total PCBs RAL	RALs for Other Chemicals	Area Remediated
(12)	12 mg/kg OC	See FS Table 6-1 (same for all alternatives)	121 of 157 acres
(7.5)	7.5 mg/kg OC		132 of 157 acres
(5.0)	5.0 mg/kg OC		140 of 157 acres

Notes:
FS – Feasibility Study
mg/kg – milligrams per kilogram
OC – organic carbon
PCB – polychlorinated biphenyl
RAL – remedial action level

2.2 Remedial Technologies

The remedial technologies are additional components that were modified to produce the array of alternatives. The remedial technologies were screened in Section 7 for potential application in specific areas of the EW, called Construction Management Areas (CMAs;

FS Table 7-3). For the purpose of alternative development, the CMAs are grouped into "open-water," which are areas with relatively unrestricted access for remediation, and "limited access areas," which are areas that are difficult to access with typical remediation equipment, and include both the underpier areas and the low bridge areas of the Sill Reach (FS Figure 7-1). The open-water remedial technologies are discussed in Section 2.2.1 herein, and the limited access area remedial technologies are discussed in Section 2.2.2.

2.2.1 Open-water Remedial Technologies

The open-water CMAs have been grouped based on areas with similar characteristics that affect remediation, including structural restrictions, waterway use, habitat, and water depth requirements (FS Section 7.7). Based on these characteristics, remedial technologies were screened for applicability in each area (FS Section 7.8). This section uses the CMA groups and the retained technologies to form three open-water technology options (labeled 1, 2, and 3) that provide a range of potential remediation approaches. The open-water technology options generally increase in the amount of sediment removal from Option 1 through Option 3; however, all open-water technology options rely primarily on dredging due to site use and navigational water depth restrictions in most of the open-water areas of the waterway. Table 2-2 presents the technology options for the open-water CMAs.

Table 2-2
Open-water Technology Options for Alternatives Development

Open-water Option	Navigation Channel and Berth Areas (110 acres)[1]	Shallow Main Body (22 acres)[1]	Nearshore (8 acres)[1]	West Seattle Bridge (2 acres)[1]
	CMAs: - *Federal Navigation Channel – South* - *Federal Navigation Channel – North* - *Deep Draft Berth Areas (T-18, T-30, T-25)* - *Slip 27 Channel* - *Slip 36/T-46 Offshore* - *T-30 Nearshore* - *Junction Reach* - *Communication Cable Crossing*	*CMAs:* - *Shallow Main Body – North and South* - *Former Pier 24 Piling Field*	*CMAs:* - *Mound Area/Slip 27 Shoreline* - *Coast Guard Nearshore*	*CMA:* - *Sill Reach – West Seattle Bridge*
1	• Removal • Partial Removal with ENR-nav • ENR-nav	• Partial Removal and Cap	• Partial Removal and Cap	• ENR-sill
2	• Removal	• Partial Removal and Cap	• Partial Removal and Cap	• ENR-sill
3	• Removal	• Removal	• Partial Removal and Cap	• Removal

Notes:
1. The area for the CMAs represents the total area of the CMAs. The remediation area within the CMAs depends on the RAL set used for the alternative.

CMA – Construction Management Area
ENR – enhanced natural recovery
RAL – remedial action level
T – Terminal

2.2.2 Limited Access Area Remedial Technologies

The limited access areas of the EW include the underpier CMAs and the two low bridges on the Sill Reach; these are referred to as the "limited access area CMA groups" for simplicity. These areas present particular challenges for remediation and, as such, have a different range of technology options for this alternative screening (FS Section 7.8). The retained technologies in these areas have been put together in six different limited access area technology options (labeled A through E, plus a variant of C called C+). These options generally increase in cost from Option A through Option E. Table 2-3 presents the six limited access area technology options.

Table 2-3
Limited Access Area Technology Options for Alternatives Development

Limited Access Area Option	Underpier (15 acres)[1]	Sill Reach – Low Bridges (2 acres)[1]
	CMA: *– Underpier areas*	*CMAs:* *– Spokane Street Bridge* *– Railroad Bridge*
A	• MNR	• MNR (subtidal) • ENR-sill (intertidal)
B	• In situ Treatment	• ENR-sill
C	• Removal for PCBs or Hg > CSL • In situ treatment elsewhere	• ENR-sill
C+	• Removal ***followed by in situ treatment*** for PCBs or Hg > CSL • In situ treatment elsewhere	• ENR-sill
D	• Removal	• ENR-sill
E	• Removal followed by in situ treatment	• ENR-sill

Notes:
1. The area for the CMAs represents the total area of the CMAs. The remediation area within the CMAs depends on the RAL set used for the alternative.

CMA – Construction Management Area
CSL – cleanup screening level
ENR – enhanced natural recovery
Hg – mercury
MNR – monitored natural recovery
PCB – polychlorinated biphenyl
RAL – remedial action level

2.3 Suite of Alternatives for Screening

From the three open-water technology options, the six limited access area technology options, and the three RAL sets, 16 combinations were established in coordination with EPA to support the comparison of each of the varied components. These 16 site-wide remedial alternatives are listed below and depicted in Figures 2-1 through 2-16. RALs are the same in all alternatives except for total PCB, which vary as noted below.

- No Action
- 1A(12)
- 1B(12)
- 1C+(12)
- 2A(12)
- 2B(12)
- 2C(12)
- 2C+(12)
- 3B(12)
- 3C+(12)
- 3D(12)
- 2C+(7.5)
- 3C+(7.5)
- 3E(7.5)
- 2C+(5.0)
- 3D(5.0)
- 3E(5.0)

Alternatives Key:

Open-water

1 – Removal with capping and ENR where applicable
2 – Removal with capping where applicable
3 – Maximum removal

Limited Access Area

A – MNR
B – In situ treatment
C – Removal for PCBs or Hg > CSL; in situ treatment elsewhere exceeding RALs
C+ – Removal ***followed by in situ treatment*** for PCBs or Hg > CSL; in situ treatment elsewhere exceeding RALs
D – Diver-assisted hydraulic dredging
E – Diver-assisted hydraulic dredging followed by in situ treatment

RALs

(12) – 12 mg/kg OC for PCBs plus the RALs for other chemicals
(7.5) – 7.5 mg/kg OC for PCBs plus the RALs for other chemicals
(5.0) – 5.0 mg/kg OC for PCBs plus the RALs for other chemicals

3 COMPARISON OF ALTERNATIVES

This section presents the focused screening of alternatives based on the CERCLA criteria of effectiveness, implementability, and cost. When considered together, the criteria support the comparison of cost-effectiveness for the alternatives. The approach used for this focused screening is to employ the tools that have been developed for the FS (e.g., predictive models, and cost and construction duration estimating tools) as the key metrics that are most representative of screening criteria of effectiveness, implementability, and cost. Focusing on these key metrics supports understanding of the differences among the alternatives, how the components used in developing the alternatives influences each alternative, and selection of an appropriate range of technologies and cost-effective alternatives to be retained for the detailed analysis of alternatives (FS Sections 9 and 10). Effectiveness and implementability criteria described in this screening should not be confused with similar CERCLA criteria defined in detail in FS Sections 9 and 10; the criteria and metrics presented in this appendix are for the alternatives screening only. The following sections describe the metrics and the ratings used in the screening for effectiveness, implementability, and cost of each alternative.

3.1 Effectiveness Screening Metric

The effectiveness screening metric includes short-term effectiveness, long-term effectiveness, and reduction in toxicity due to treatment (EPA 1988). For this screening analysis, the alternatives were rated based on the predicted site-wide spatially-weighted average concentrations (SWACs) for total PCBs and associated estimated human health risks based on seafood consumption. This is a key metric for the effectiveness screening metric because total PCBs is one of the important risk drivers at the site, contributing most to site-wide risk for RAOs 1, 3, and 4 (human health seafood consumption, benthic toxicity, and ecological risk, respectively). In addition, total PCBs SWACs provide an indication of the risk reduction trends for other COCs that are generally co-located with PCBs and contribute less to risk (FS Section 9). The PCB SWAC calculation also takes into account reduction in bioavailability due to in situ treatment, and therefore addresses reduction in toxicity due to treatment per EPA guidance on evaluating effectiveness. Finally, SWAC calculations include the contribution of mixing of subsurface sediments, and therefore incorporates the effect of subsurface contamination into SWAC predictions into the assessment of effectiveness.

Other metrics that are used to evaluate short-term and long-term effectiveness in the detailed evaluation of alternatives are included in FS Sections 9 and 10 for each of the alternatives retained for detailed analysis.

The PCB SWACs should be interpreted with consideration for the overall accuracy of the analysis. FS Appendix J presents a sensitivity analysis to understand the effect of varying input values for each parameter; the predicted SWACs in that analysis vary by up to approximately +/-40%, depending on the parameter varied (e.g., see Figure 4b of FS Appendix J). Analytical variability also effects the range of certainty for both the pre-construction baseline conditions and the long-term measurement of alternative performance. Because of these modeling and analytical constraints, differences in SWACs of less than 5 to 10 micrograms per kilogram (μg/kg) should be interpreted with caution.

Also note that the differences in predicted risk are considerably less than the differences in SWAC because small variations in sediment concentrations do not directly translate into different risk outcomes and, in part, because of the levels of PCBs present in surface water that contribute to elevated risk (see FS Section 9.2.4 and SRI Section 6 [Windward and Anchor QEA 2014]).

To understand the effect of each of the three remedial alternative components (RALs, open-water technology option, and limited access area technology option) on predicted PCB SWACs, it is helpful to analyze these components in isolation, as performed in the following sections.

3.1.1 Effect of Varying RALs

The effect of the PCB RAL on the predicted site-wide SWACs can be shown by isolating alternatives that that use the same open-water technology option and same limited access area technology option but different PCB RAL. Figure 3-1 shows the predicted site-wide SWACs over time for Alternatives 2C+(12), 2C+(7.5), and 2C+(5.0) to demonstrate the effect of changing the RAL only. The predicted SWACs over time are almost identical for the alternatives, and the differences are not meaningful and are well within the uncertainty of the analysis. The predicted excess cancer risks over time are identical (Table 3-1). Based on this information, reducing the RAL below 12 milligrams per kilogram of organic carbon (mg/kg OC) results in additional remediation area without improving effectiveness of the remediation. A RAL lower than 12 mg/kg OC for PCBs does not improve effectiveness because the RAL of 12 mg/kg OC along with the other COC RALs already results in the remediation of the majority of the waterway. In addition, other factors have a larger influence on the SWAC than the RAL, such as the estimated post-construction surface sediment concentration, the concentrations of incoming sediment, and remediation option used in limited access areas.

3.1.2 Effect of Varying Open-water Technology Option

Similar to the RAL analysis above, the effect of the open-water technology option on the predicted site-wide SWACs can be shown by isolating alternatives that utilize the same limited access area technology option and PCB RAL, but have different open-water technology options. Figure 3-2 shows the predicted site-wide SWACs over time for Alternatives 1B(12), 2B(12), and 3B(12) to demonstrate the effect of changing the open-water technology option only (figure shown with the same y-axis range as Figure 3-1 for comparison). The curves are almost identical for the alternatives, and the differences are not meaningful and are well within the uncertainty of the analysis. The predicted excess cancer risks over time are identical (Table 3-1). Varying the open-water technology group did not have a large effect on the site-wide SWACs for the remedial alternatives because the range of technology options in the open-water areas of the EW is limited by site use considerations. Dredging is the primary remedial technology used in all technology options because other remedial technologies are limited by navigational depth requirements and propwash forces in the EW. Within this narrow range of technology options, increasing of the amount of removal in the open-water area results in a narrow range of SWAC outcomes and no change in health risks, and thus does not change effectiveness screening metric outcomes.

3.1.3 Effect of Varying Limited Access Area Technology Option

The component that explains most of the variation between the alternatives is the limited access area technology option. Figure 3-3 shows the predicted SWAC over time for one alternative with each of the six limited access area technology options (figure shown with the same y-axis range as Figures 3-1 and 3-2 to facilitate comparison). These options generally fall into three groups based on predicted SWAC. Limited Access Area Technology Options A and D have higher year 0 post-construction SWACs. Limited Access Area Technology Option D is predicted to show improvement over time, whereas Limited Access Area Technology Option A is predicted to show improvement over time but to sustain higher concentrations overall. Alternatives with Limited Access Area Technology Options B and C+ track similarly over time, and Limited Access Area Technology Option C begins with year 0 concentrations somewhat higher than Options B and C+ but then tracks similarly to each of them over time. Limited Access Area Technology Option E has a lower predicted SWAC than the other technology options. However, if model and analytical uncertainties are considered, Options B, C, C+, D, and E have similar outcomes after year 5 post-construction.

3.1.4 Cumulative Effect on Effectiveness Screening Metric

The cumulative effect of the three components for all alternatives (i.e., open-water technology option, limited access technology option, and RAL) is presented in Table 3-1. For all alternatives, the table presents the PCB SWACs predicted by the box model (FS Section 5 and Appendix J) and associated excess cancer risks for Adult Tribal reasonable maximum exposure scenarios for seafood consumption (RAO 1). The results are presented for the average of 0 to 40 years following construction.

Table 3-1

Effectiveness – Box Model Results for Total PCBs

Alternative	Average for 0 to 40 years Following Construction		
	SWAC for Total PCBs (µg/kg Considering Bioavailability)[a,b]	Adult RME Excess Cancer Risk from PCBs (Considering Bioavailability)	Rating
No action	300	6×10^{-4}	Poor
1A(12)	99	3×10^{-4}	Fair
1B(12)	62	2×10^{-4}	Good
1C+(12)	58	2×10^{-4}	Good
2A(12)	99	3×10^{-4}	Fair
2B(12)	62	2×10^{-4}	Good
2C(12)	61	2×10^{-4}	Good
2C+(12)	58	2×10^{-4}	Good
3B(12)	62	2×10^{-4}	Good
3C+(12)	58	2×10^{-4}	Good
3D(12)	62	2×10^{-4}	Good
2C+(7.5)	56	2×10^{-4}	Good
3C+(7.5)	56	2×10^{-4}	Good
3E(7.5)	52	2×10^{-4}	Good
2C+(5)	56	2×10^{-4}	Good
3D(5)	61	2×10^{-4}	Good
3E(5)	51	2×10^{-4}	Good

Notes:

a. SWACs are rounded to 2 significant digits. The PCB SWACs should be interpreted with consideration for the overall accuracy of the analysis. FS Appendix J presents a sensitivity analysis to understand the effect of varying input values for each parameter; the predicted SWACs in that analysis vary by up to approximately +/-40%, depending on the parameter varied. See Section 3-1 of this appendix.

b. Alternatives that use in situ treatment were estimated to result in a 70% reduction in bioavailability in those areas (see FS Section 7.2.7.1.1). The calculated SWACs include a reduction in concentration due to in situ treatment, when used.

µg/kg – micrograms per kilogram
FS – Feasibility Study
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
SWAC – spatially-weighted average concentration

The results in Table 3-1 summarize the factors discussed in Sections 3.1.1 through 3.1.3 herein. For the purpose of this screening, the average PCB SWAC in the years 0 to 40 following construction has been selected as the key metric for evaluating effectiveness because it summarizes the complex box model results into a single value. In addition, human health risks are based on exposures over long durations, and therefore an average SWAC over a longer timeframe is a single way of bringing in several factors affecting effectiveness into a single metric.

The alternatives have been rated by the effectiveness screening metric based on a three-tiered scale: poor, fair, and good. The alternatives have been rated based on the predicted Adult Tribal reasonable maximum exposure (RME) excess cancer risk (considering bioavailability) associated with the 40-year average SWACs. The "poor" rating was assigned to the No Action Alternative, with Adult Tribal RME excess cancer risk of 6×10^{-4} (average PCBs SWAC of 300 μg/kg). The "fair" rating was assigned to Alternatives 1A(12) and 2A(12), with Adult Tribal RME excess cancer risk of 3×10^{-4} (average PCBs SWAC of 99 μg/kg). A "good" rating was assigned to the remaining alternatives with Adult Tribal RME excess cancer risk of 2×10^{-4} (average PCBs SWAC of 51 to 62 μg/kg).

3.2 Implementability Screening Metric

Generally, all of the alternatives are both technically and administratively feasible to implement. The alternatives screened in this appendix all rely primarily on removal and will have feasibility challenges associated with: 1) dredging large quantities of sediment in an active container terminal area; 2) permitting and constructing transloading operations over the course of up to 14 construction seasons; and 3) transporting and disposing of large quantities of sediment in a landfill. In this evaluation, the construction timeframe is used as one indicator for the degree of implementation challenges expected for each alternative in open-water areas, because the technical and administrative challenges are expected to scale with the number of construction seasons mobilized. Landfills with sufficient capacity for dredged material are located in Eastern Washington and Eastern Oregon.

In addition, limited access area remediation has additional technical challenges beyond those in the open-water. In particular, the implementation of underpier diver-assisted hydraulic dredging will be challenging to implement due to dredging below active shipping terminals, uncertainty in removing sediment from riprap surfaces, diver safety, and barge dewatering and treatment of the sediment slurry. In addition, the outcome of diver-assisted dredging is highly uncertain for this work. For this screening evaluation, the construction timeframe for diver-assisted hydraulic dredging is used as another indicator for the degree of implementability challenges during remediation. Additional criteria are used to evaluate implementability under the CERCLA criteria evaluation in the analysis and comparison of alternatives in FS Sections 9 and 10; this appendix evaluates implementability for the alternative screening only.

Table 3-2 presents the implementability rating of the alternatives. Implementability considered both the total construction timeframe and the underpier diver-assisted hydraulic dredging timeframes for the alternatives; however, diver-assisted hydraulic dredging was the key differentiating factor due to having greater implementability challenges than remediation in open water areas. The No Action Alternative is rated “excellent” for implementability because no construction is performed. Alternatives that have construction durations of 10 years or less and no duration of underpier hydraulic dredging (Alternatives 1A(12), 1B(12), 2A(12), and 2B(12)) are rated “good” because they will be easier to implement than the other alternatives. Alternatives with 12 years or less of construction but only estimated to have 2 years of diver-assisted hydraulic dredging (Alternatives 1C+(12), 2C(12), 2C+(12), 3C+(12), 2C+(7.5), 3C+(7.5), and 2C+(5.0)) are rated “fair” because they require the mobilization of extensive underpier hydraulic dredging, but do not require divers to work the EW for a decade. The alternatives that require more than 10 years of diver-assisted hydraulic dredging (Alternatives 3D(12), 3E(7.5), 3D(5), and 3E(5.0)) score “poor” because of the dangerous and challenging nature of the work and the high uncertainty in the overall effectiveness of diver-assisted dredging, relative to other limited access area technologies.

Table 3-2
Implementability Screening Metric

Alternative	Construction Timeframe (years)	Underpier Dredging Timeframe (years)	Rating for Implementability
No Action	0	0	Excellent
1A(12)	9	0	Good
1B(12)	9	0	Good
1C+(12)	9	2	Fair
2A(12)	10	0	Good
2B(12)	10	0	Good
2C(12)	10	2	Fair
2C+(12)	10	2	Fair
3B(12)	10	0	Good
3C+(12)	10	2	Fair
3D(12)	13	11	Poor
2C+(7.5)	11	2	Fair
3C+(7.5)	11	2	Fair
3E(7.5)	13	12	Poor
2C+(5)	12	2	Fair
3D(5)	14	12	Poor
3E(5)	14	12	Poor

3.3 Cost Screening Metric

Alternative costs were estimated by using the cost estimate in FS Appendix E. Costs are presented in Table 3-3 and include construction costs (e.g., mobilization and dredge material disposal), non-construction costs (e.g., oversight and permitting), long-term monitoring, tax, and contingency. The costs are broken up into cost ranges for the purpose of assigning alternative rankings.

The No Action Alternative is rated "excellent" because it includes monitoring costs only. Alternatives with costs between $250 and $285 million (Alternatives 1A(12), 1B(12), 1C+(12), 2A(12), and 2B(12)) were rated "good" because they have mid to low costs compared to the other alternatives. Alternatives with costs between $290 and $350 million (Alternatives 2C(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), 3C+(7.5), and 2C+(5.0)) were rated "fair" because they have mid to high costs compared to the other alternatives. Finally, alternatives with costs between $370 and $440 million (Alternatives 3D(12), 3E(7.5), 3D(5.0), and 3E(5.0)) were rated "poor" because they are more expensive that the other alternatives.

Table 3-3
Cost

Alternative	Cost ($ Million)	Rating
No Action	$0.95	Excellent
1A(12)	$256	Good
1B(12)	$264	Good
1C+(12)	$277	Good
2A(12)	$276	Good
2B(12)	$284	Good
2C(12)	$296	Fair
2C+(12)	$297	Fair
3B(12)	$298	Fair
3C+(12)	$310	Fair
3D(12)	$377	Poor
2C+(7.5)	$326	Fair
3C+(7.5)	$333	Fair
3E(7.5)	$411	Poor
2C+(5.0)	$345	Fair
3D(5.0)	$426	Poor
3E(5.0)	$435	Poor

4 SCREENING OF ALTERNATIVES

Table 4-1 summarizes the results of the alternative ratings for the screening metrics for effectiveness, implementability, and cost, and presents the screening decision and rationale for each alternative. Nine alternatives have been retained (including No Action) for detailed analysis, and seven alternatives have been eliminated.

Table 4-1 provides a summary of the category ratings for the alternatives that went into the screening decision. For some of the alternatives, a finer-scaled cost-benefit analysis is helpful to better demonstrate the differences between the alternatives; Figure 4-1 presents a scatter plot of the alternatives (excluding the No Action Alternative) with the predicted PCBs SWACs (averaged over years 0 through 40 post-construction), plotted against cost. The dashed line indicates the boundary representing the lowest SWAC at any given cost. Generally, alternatives that are closer to the knee of the dashed line have been retained for the analysis because they are likely to be more effective per unit cost. The alternatives that are further from knee of the line are more likely to be screened out because they are less effective per unit cost. However, the reader should note that the graph does not present implementability or predicted risk outcomes, which are also considered in the screening decision.

The alternatives retained for detailed analysis were generally selected to provide a wide spread of the screening metrics for implementability and cost, while emphasizing alternatives with more favorable effectiveness ratings. The purpose of this analysis is not to select a preferred alternative, but rather to identify a representative and manageable range of alternatives for detailed analysis in FS Section 9, and comparison in FS Section 10.

Alternative 1A(12) was retained for detailed analysis as the least costly alternative.
Alternative 3E(7.5) was retained to represent the maximum removal alternative.
Alternative 3E(5.0) was screened out because the additional cost over 3E(7.5) did not result in an improved effectiveness screening metric. As discussed in Section 3.1.1, modeling results showed that lowering the PCBs RAL to 5.0 mg/kg OC does not lower the predicted SWACs and associated risks, yet these alternatives result in increased implementability challenges and costs.

Table 4-1
Summary of Alternative Screening Metrics Ratings and Final Screening Results

Alternative	Effectiveness	Implementability	Cost	Screening	Rationale
No Action	Poor	Excellent	Excellent	**Retained**	Retained as a National Contingency Plan requirement
1A(12)	Fair	Good	Good	**Retained**	Retained as the least costly alternative (excluding No Action) in the suite of alternatives
1B(12)	Good	Good	Good	**Retained**	Retained due to relatively high cost-effectiveness
1C+(12)	Good	Fair	Good	**Retained**	Retained due to relatively high cost-effectiveness
2A(12)	Fair	Good	Good	Eliminated	Eliminated due to similar effectiveness and implementability as less costly Alternative 1A(12)
2B(12)	Good	Good	Good	**Retained**	Retained due to relatively high cost-effectiveness
2C(12)	Good	Fair	Fair	Eliminated	Eliminated due to reduced cost-effectiveness compared to Alternative 2C+(12) (Figure 4-1)
2C+(12)	Good	Fair	Fair	**Retained**	Retained due to fair cost-effectiveness
3B(12)	Good	Good	Fair	**Retained**	Retained due to fair cost-effectiveness and good implementability ranking
3C+(12)	Good	Fair	Fair	**Retained**	Retained due to fair cost-effectiveness
3D(12)	Good	Poor	Poor	Eliminated	Eliminated due to poor implementability and cost
2C+(7.5)	Good	Fair	Fair	**Eliminated**	Eliminated based on similar effectiveness as less costly alternatives; however, the alternative is retained per EPA directive because it is identical to Alternative 2C+(12) in the detailed analysis except with a lower RAL (7.5)
3C+(7.5)	Good	Fair	Fair	Eliminated	Eliminated due to similar effectiveness and implementability compared to less costly Alternative 3C+(12)
3E(7.5)	Good	Poor	Poor	**Retained**	Retained as the costliest alternative in the suite of alternatives to provide an end-case; also retained to maintain a representative limited access area option (Option E in the detailed evaluation of alternatives)
2C+(5.0)	Good	Fair	Fair	Eliminated	Eliminated due to similar effectiveness compared to less costly Alternative 2C+(12)
3D(5.0)	Good	Poor	Poor	Eliminated	Eliminated due to lower effectiveness compared to less costly Alternative 3E (7.5) and poor implementability and cost
3E(5.0)	Good	Poor	Poor	Eliminated	Eliminated due to similar effectiveness compared to less costly Alternative 3E(7.5)

Notes:
EPA – U.S. Environmental Protection Agency
RAL – remedial action level

Limited Access Area Technology Groups C and D employ diver-assisted hydraulic dredging without being followed by in situ treatment. Alternatives with these limited access area technology groups were all screened out because they result in limited reductions in SWAC (and resulting health risks) due to residual sediment remaining following hydraulic dredging but have large costs and implementability challenges and safety risks associated with diver-assisted dredging. Instead, Limited Access Area Technology Groups C+ and E, which employ some diver-assisted hydraulic dredging followed by in situ treatment, were retained for some alternatives.

Other alternatives were screened out based on their relative effectiveness, implementability, and cost screening metrics. Alternative 2A(12) was costlier than 1A(12), without providing additional effectiveness rating or improved implementability rating. Alternatives 2C+(7.5), 3C+(7.5), and 2C+(5.0) did not have higher effectiveness of implementability ratings when compared to less costly Alternatives 2B(12), 1C+(12), and 2C+(12).

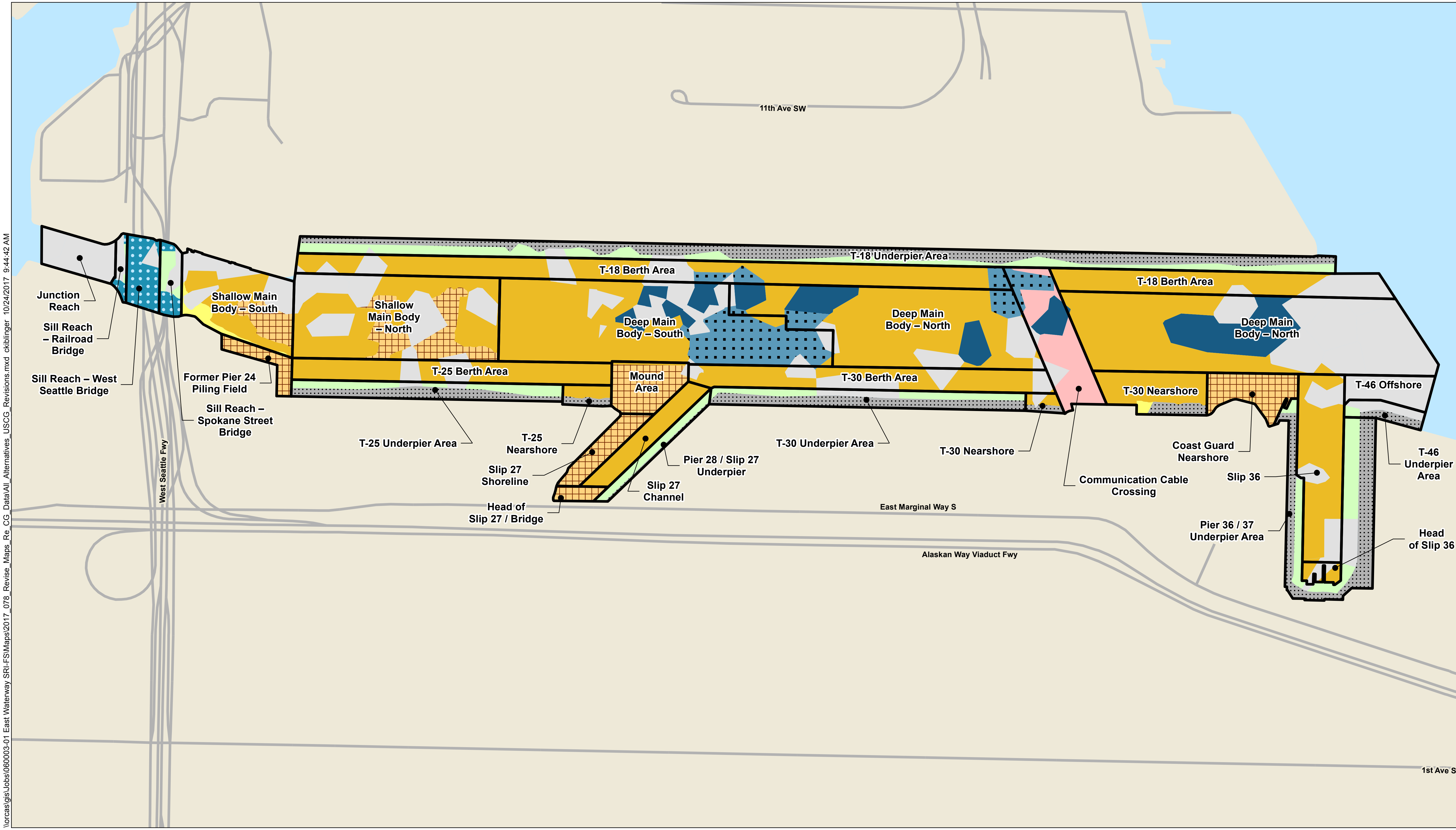
The remaining suite of alternatives are Alternatives 1A(12), 1B(12), 1C+(12), 2B(12), 2C+(12), 3B(12), 3C+(12), 3E(7.5), and the No Action Alternative.

5 REFERENCES

EPA (Environmental Protection Agency), 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA. EPA/540/G-89/004. U.S. Environmental Protection Agency, Washington, D.C. October 1988.

Windward and Anchor QEA, 2014. Supplemental Remedial Investigation. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Final. January 2014.

FIGURES



MNR
Removal
Removal and Backfill to Existing Contours
Removal to the Extent Practicable and Backfill
Partial Removal and Cap
Partial Removal and ENR-nav
ENR-sill
ENR-nav
Riprap (No Action)
No Action
CMA Boundaries

0 500 1,000
Scale in Feet

Figure 2-1
Alternative 1A(12)
Feasibility Study - Appendix L
East Waterway Study Area

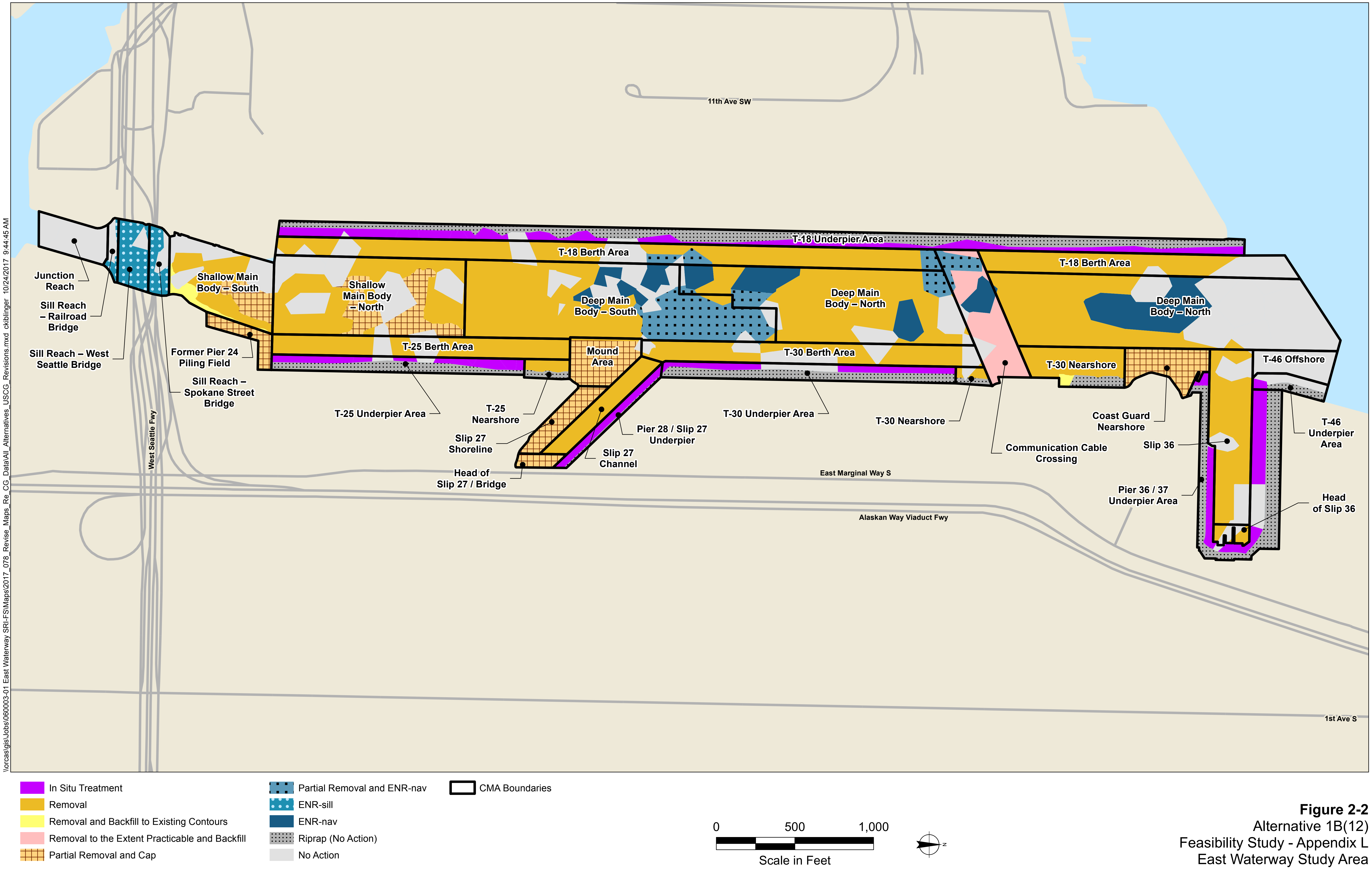


Figure 2-2
Alternative 1B(12)
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East Waterway Study Area

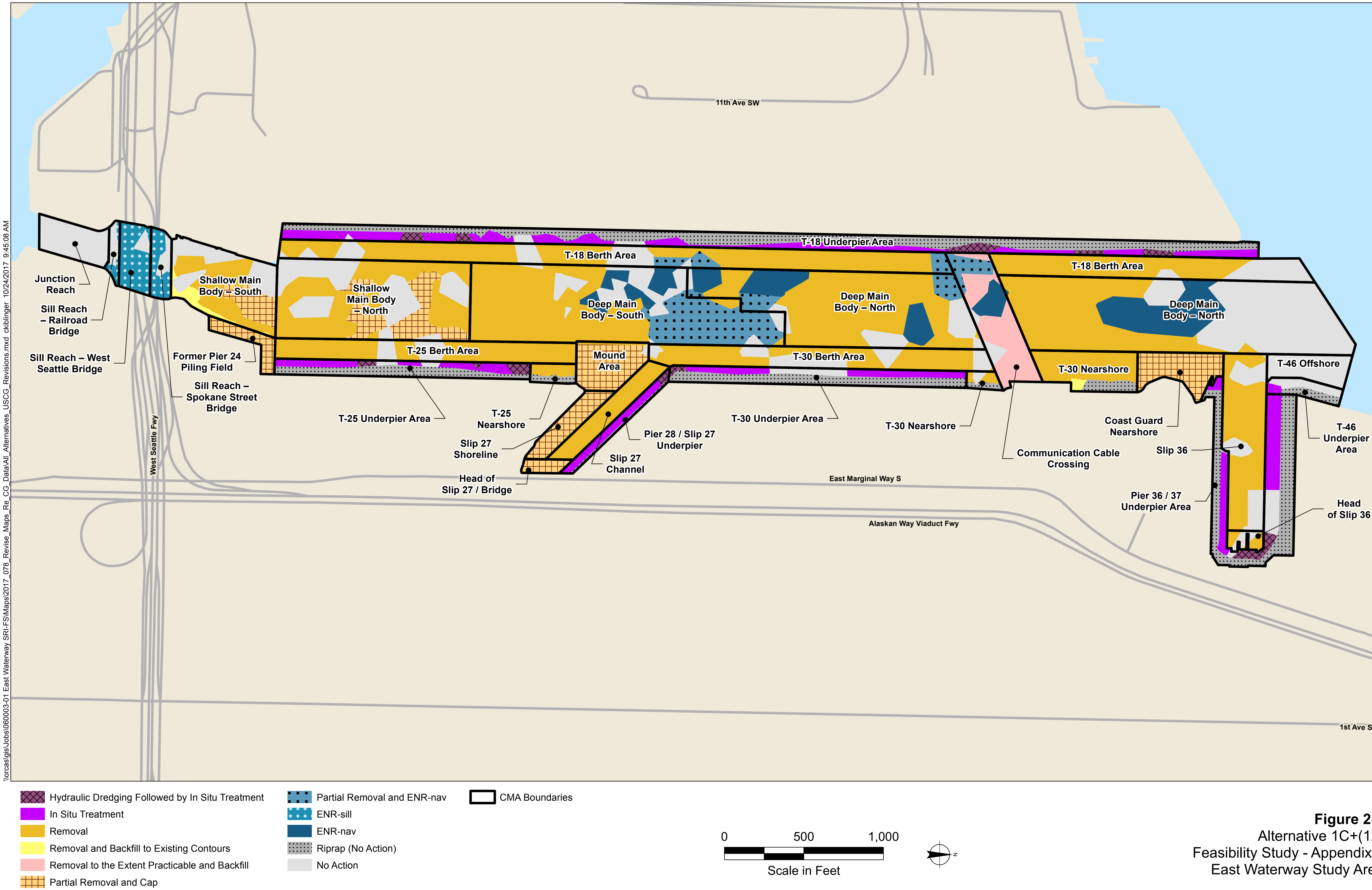


Figure 2-3
Alternative 1C+(12)
Feasibility Study - Appendix L
East Waterway Study Area

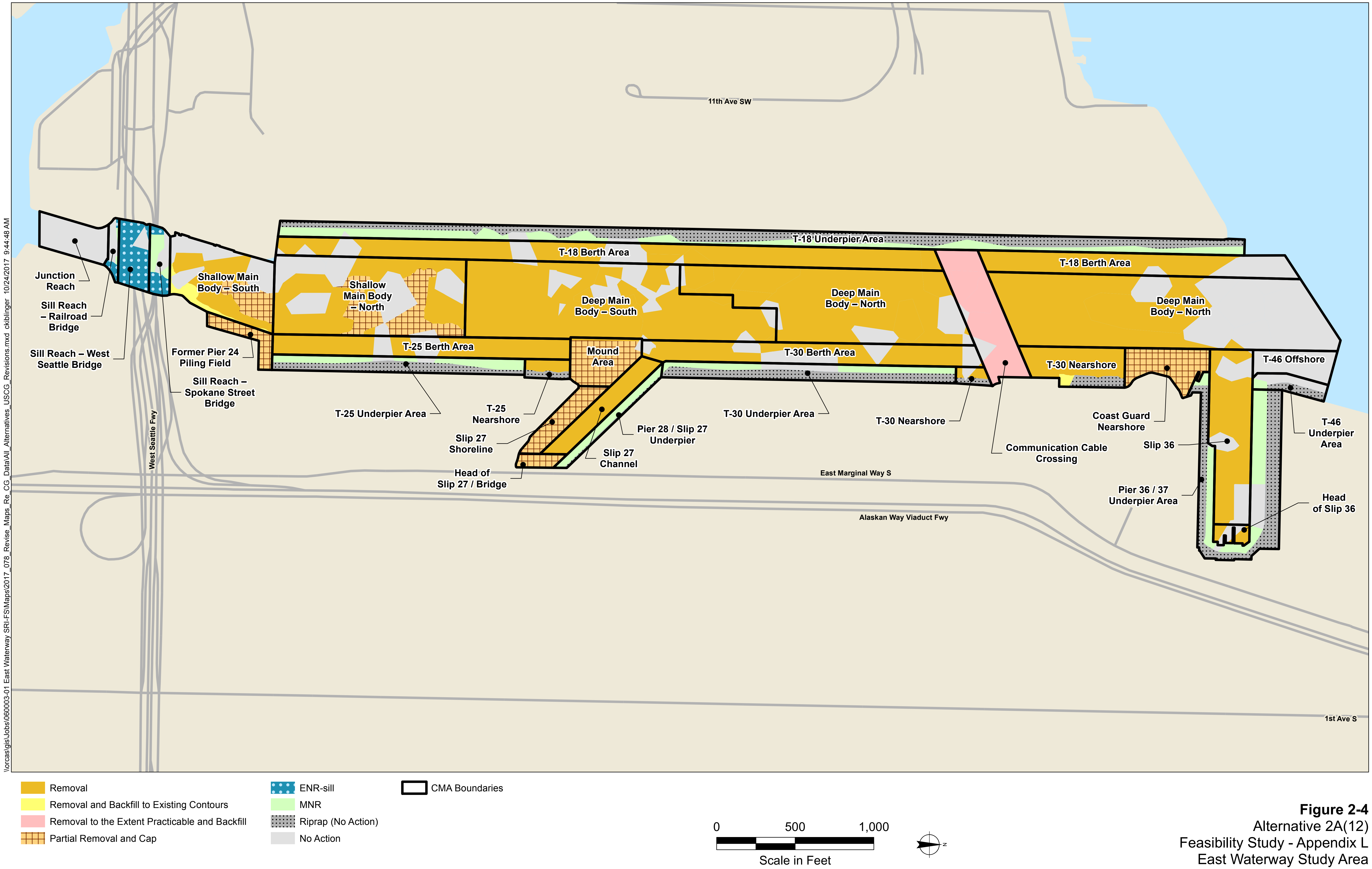
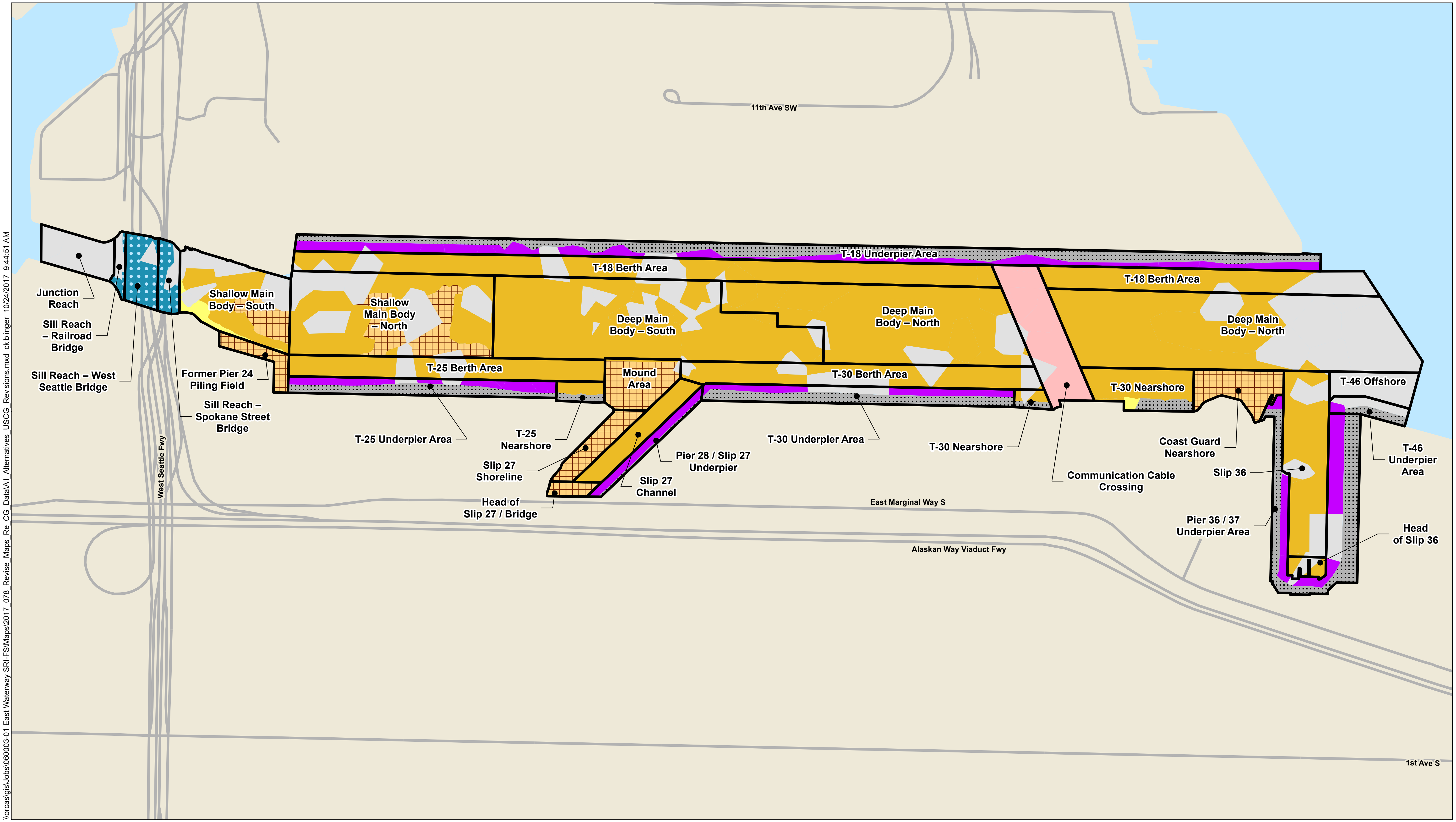


Figure 2-4
Alternative 2A(12)
Feasibility Study - Appendix L
East Waterway Study Area



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In Situ Treatment
Removal
Removal and Backfill to Existing Contours
Removal to the Extent Practicable and Backfill
Partial Removal and Cap
ENR-sill
Riprap (No Action)
No Action
CMA Boundaries

0 500 1,000
Scale in Feet

Figure 2-5
Alternative 2B(12)
Feasibility Study - Appendix L
East Waterway Study Area

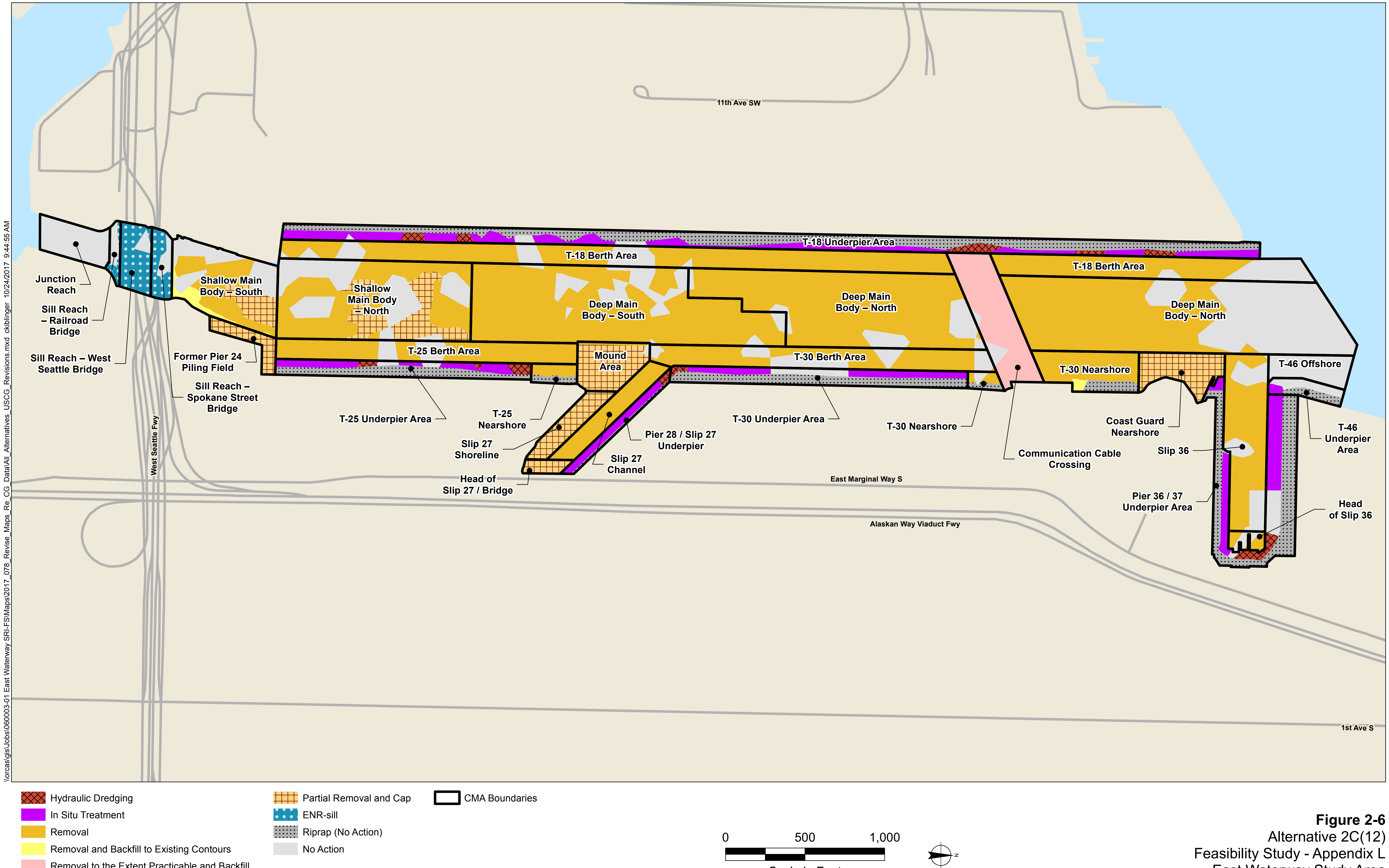


Figure 2-6
Alternative 2C(12)
Feasibility Study - Appendix L
East Waterway Study Area

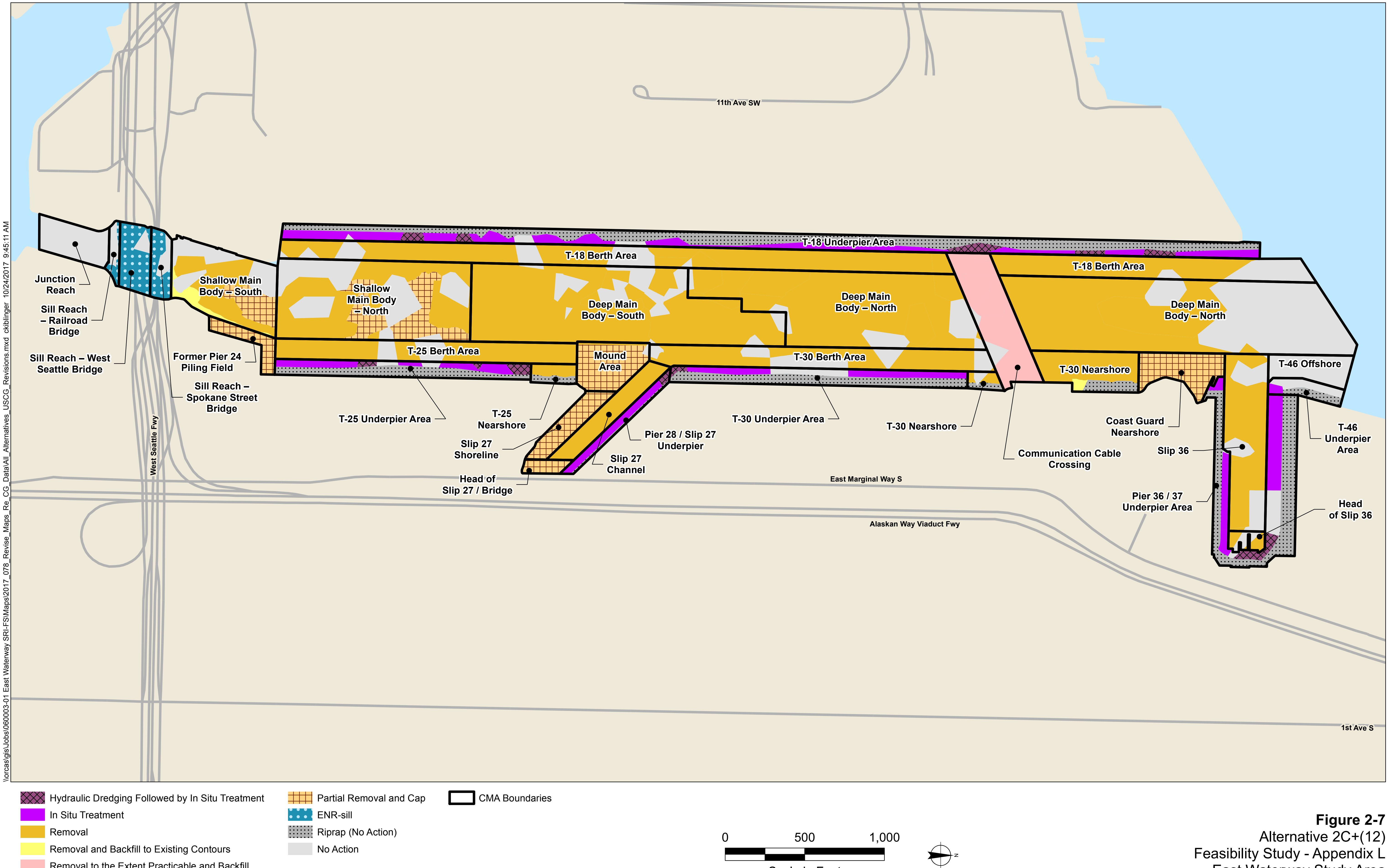
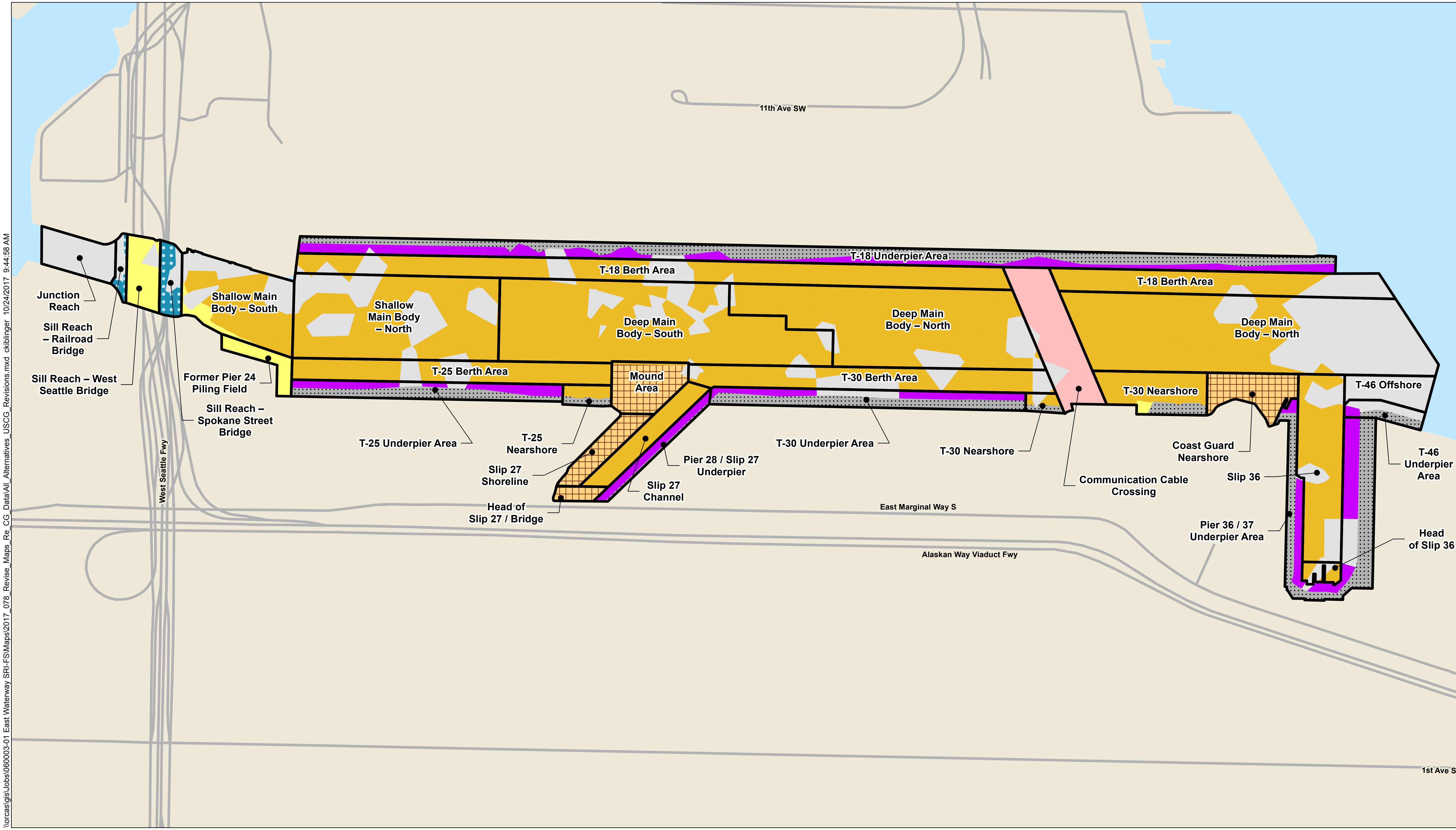


Figure 2-7
Alternative 2C+(12)
Feasibility Study - Appendix L
East Waterway Study Area



- ENR-sill
- In Situ Treatment
- Removal
- Removal and Backfill to Existing Contours
- Removal to the Extent Practicable and Backfill
- Partial Removal and Cap
- Riprap (No Action)
- No Action
- CMA Boundaries

0 500 1,000
Scale in Feet

Figure 2-8
Alternative 3B(12)
Feasibility Study - Appendix L
East Waterway Study Area

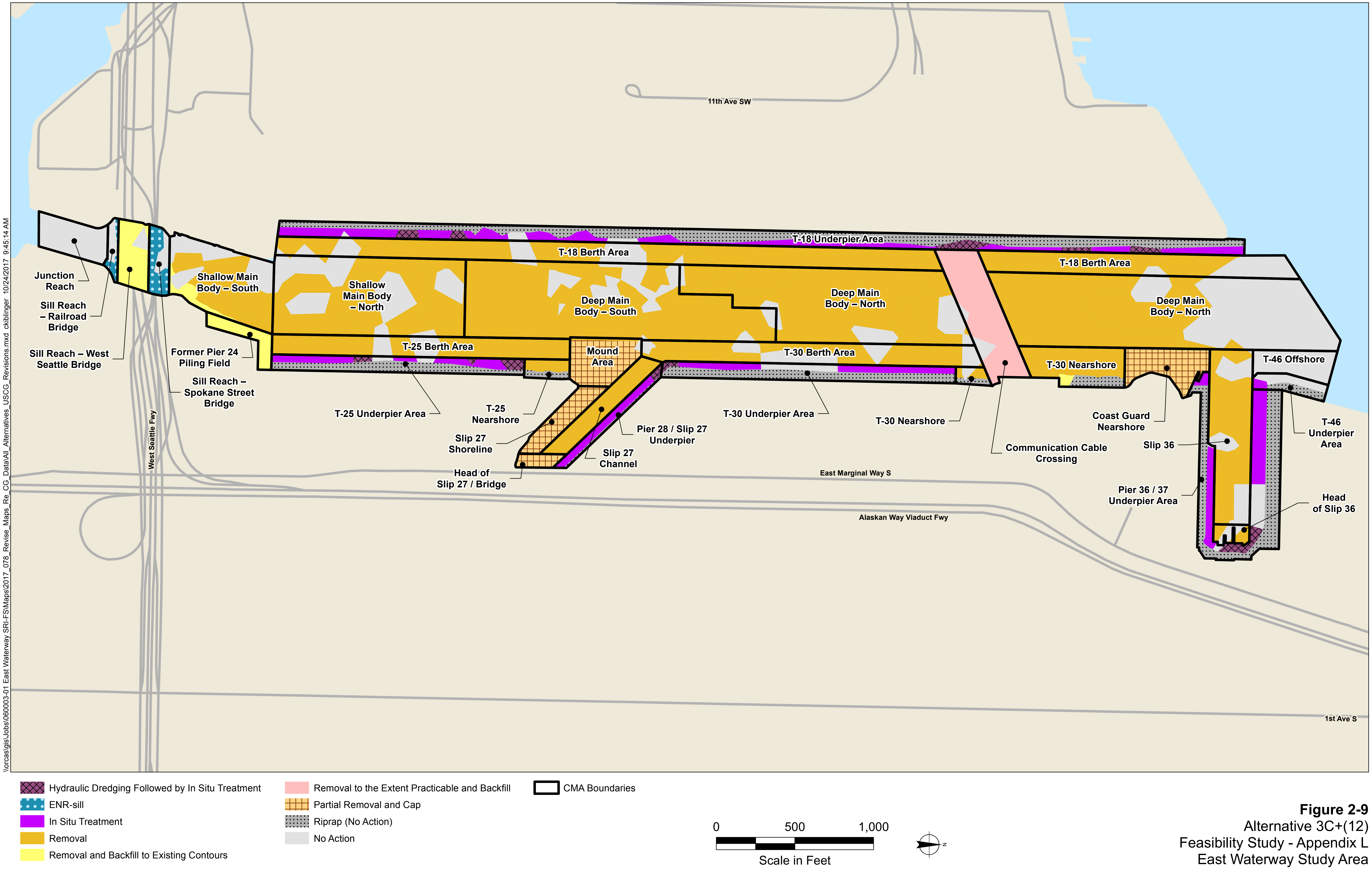


Figure 2-9
Alternative 3C+(12)
Feasibility Study - Appendix L
East Waterway Study Area

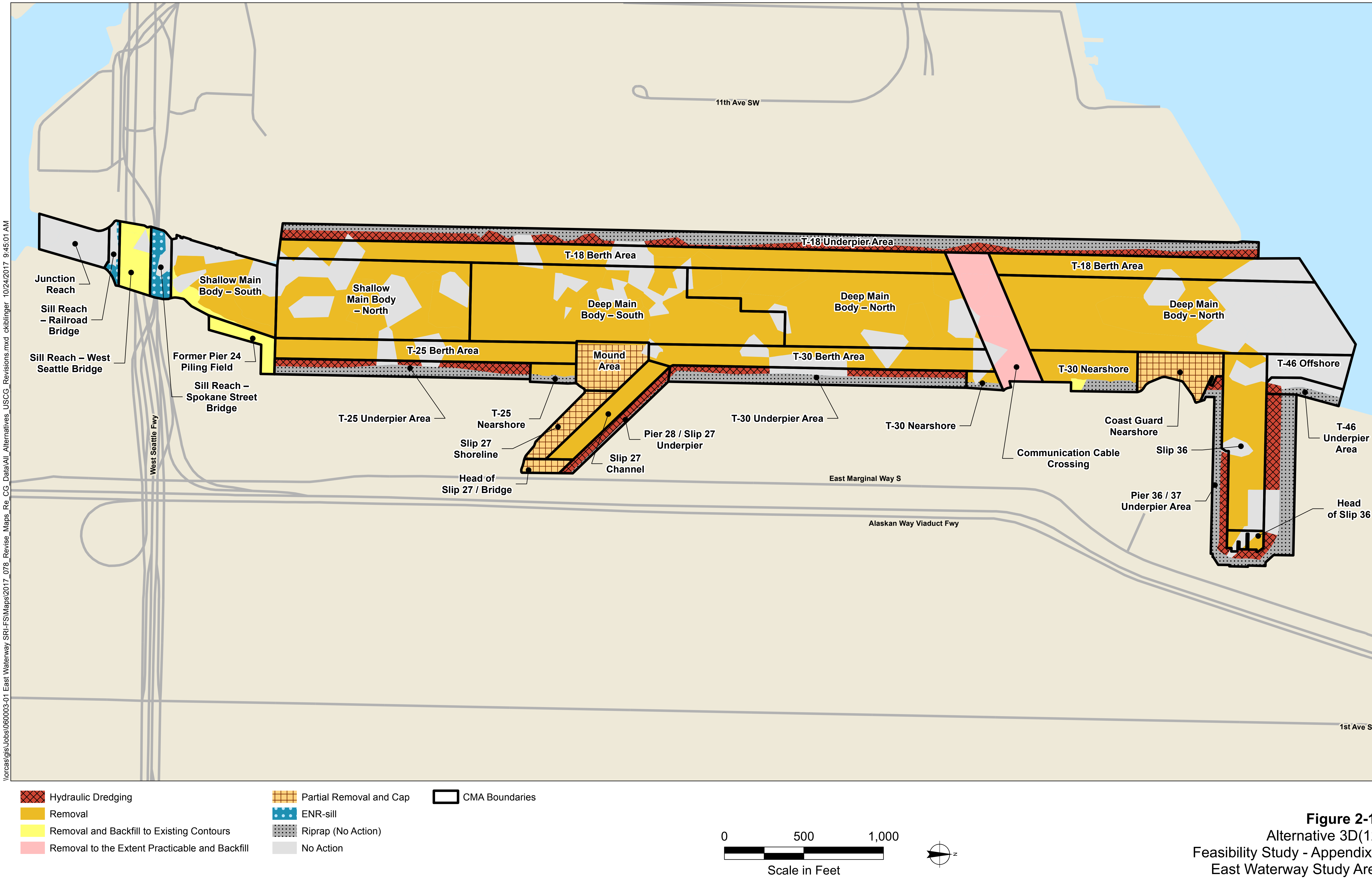


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Figure 2-10
Alternative 3D(12)
Feasibility Study - Appendix L
East Waterway Study Area

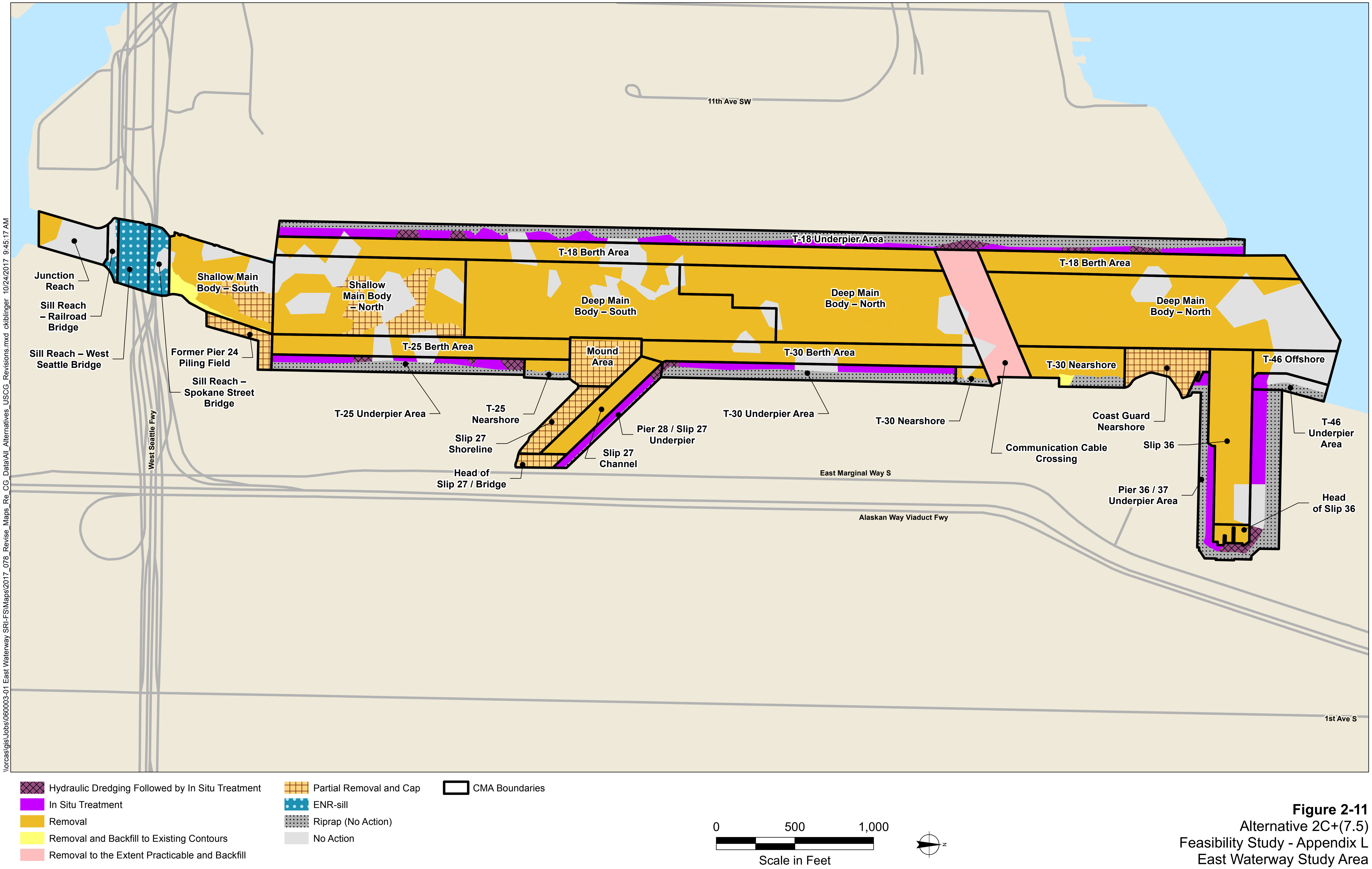

Figure 2-11
Alternative 2C+(7.5)
Feasibility Study - Appendix L
East Waterway Study Area

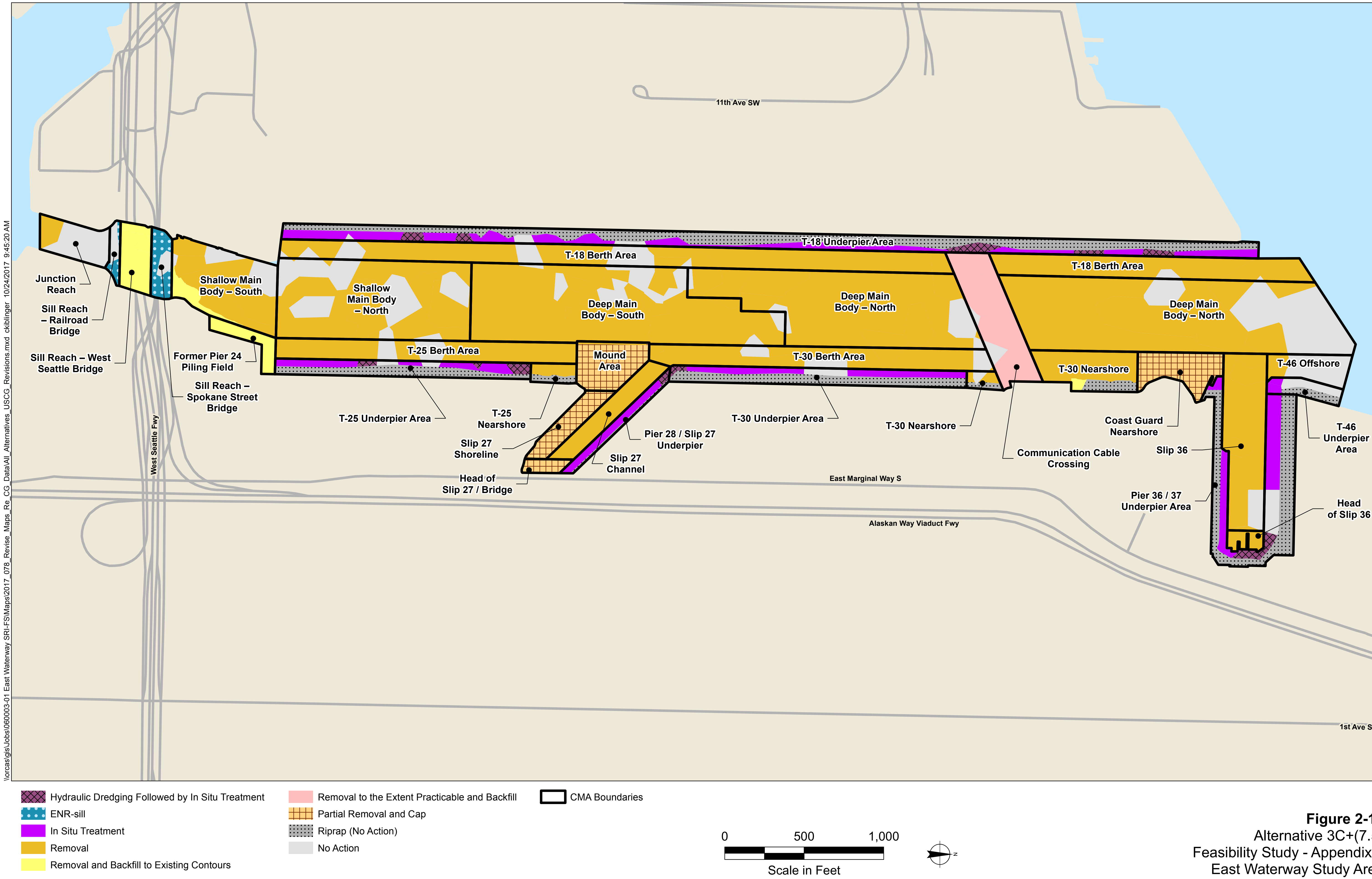

Figure 2-12
Alternative 3C+(7.5)
Feasibility Study - Appendix L
East Waterway Study Area

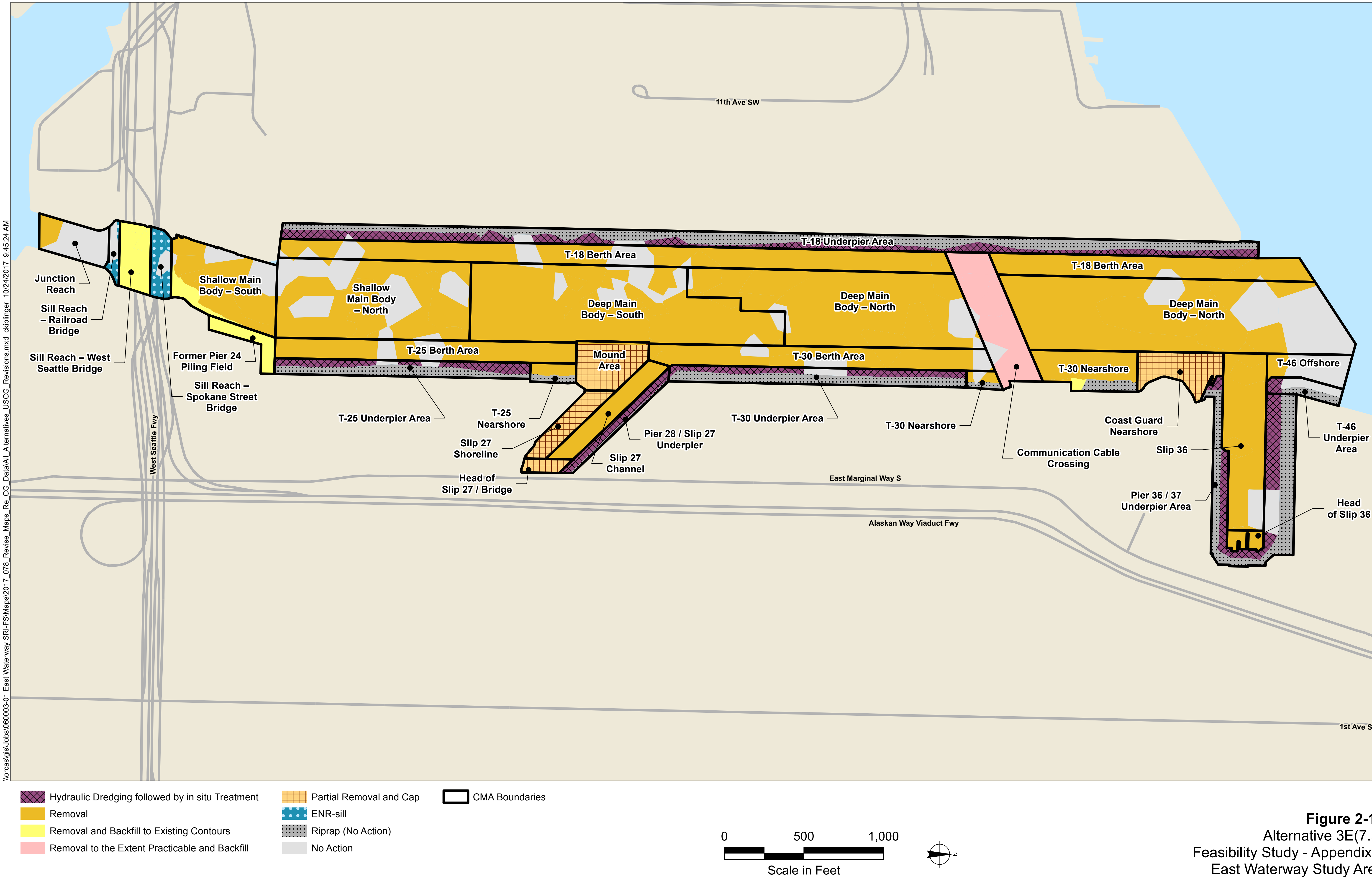

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Figure 2-13
Alternative 3E(7.5)
Feasibility Study - Appendix L
East Waterway Study Area

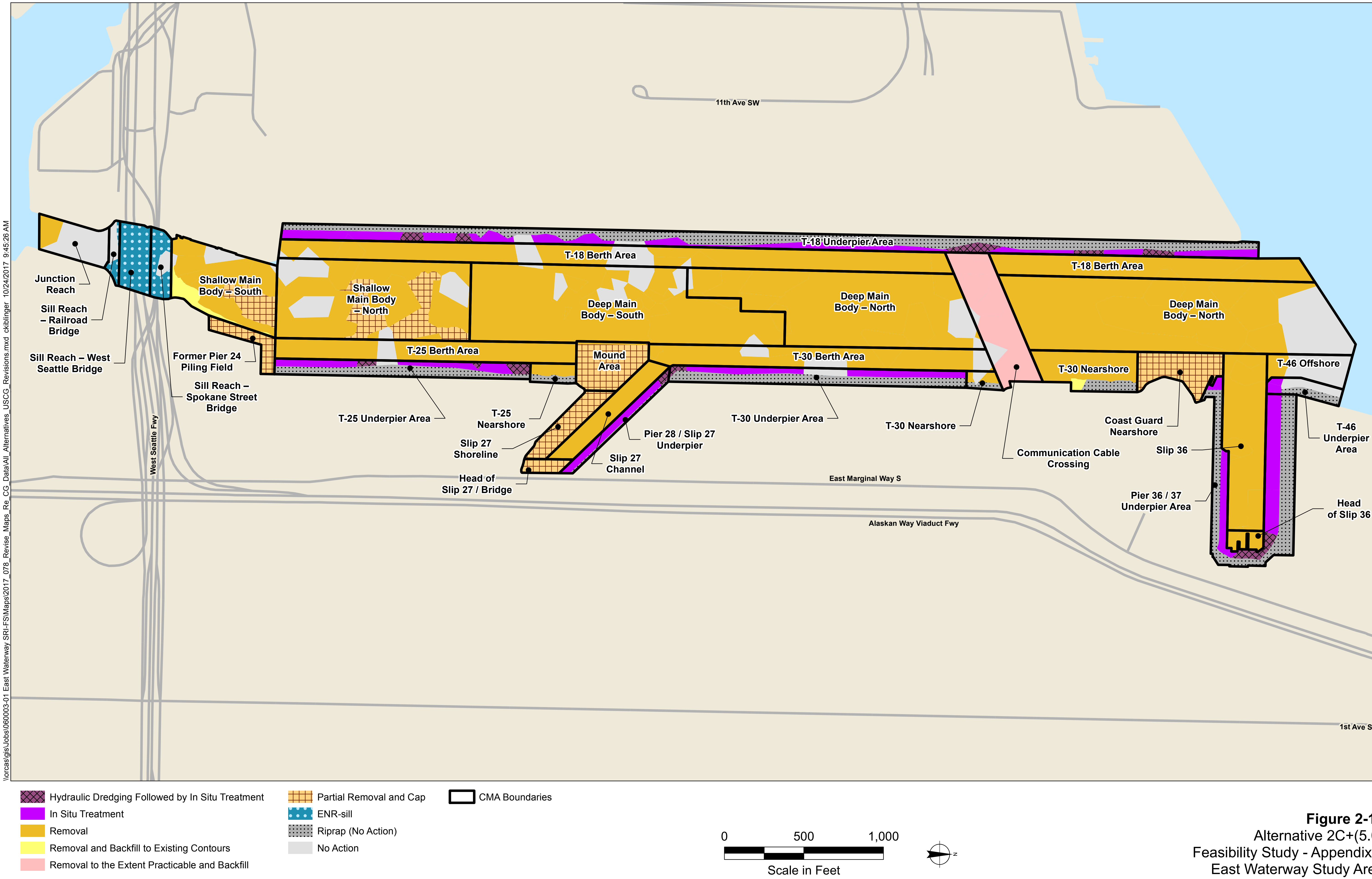

Figure 2-14
Alternative 2C+(5.0)
Feasibility Study - Appendix L
East Waterway Study Area

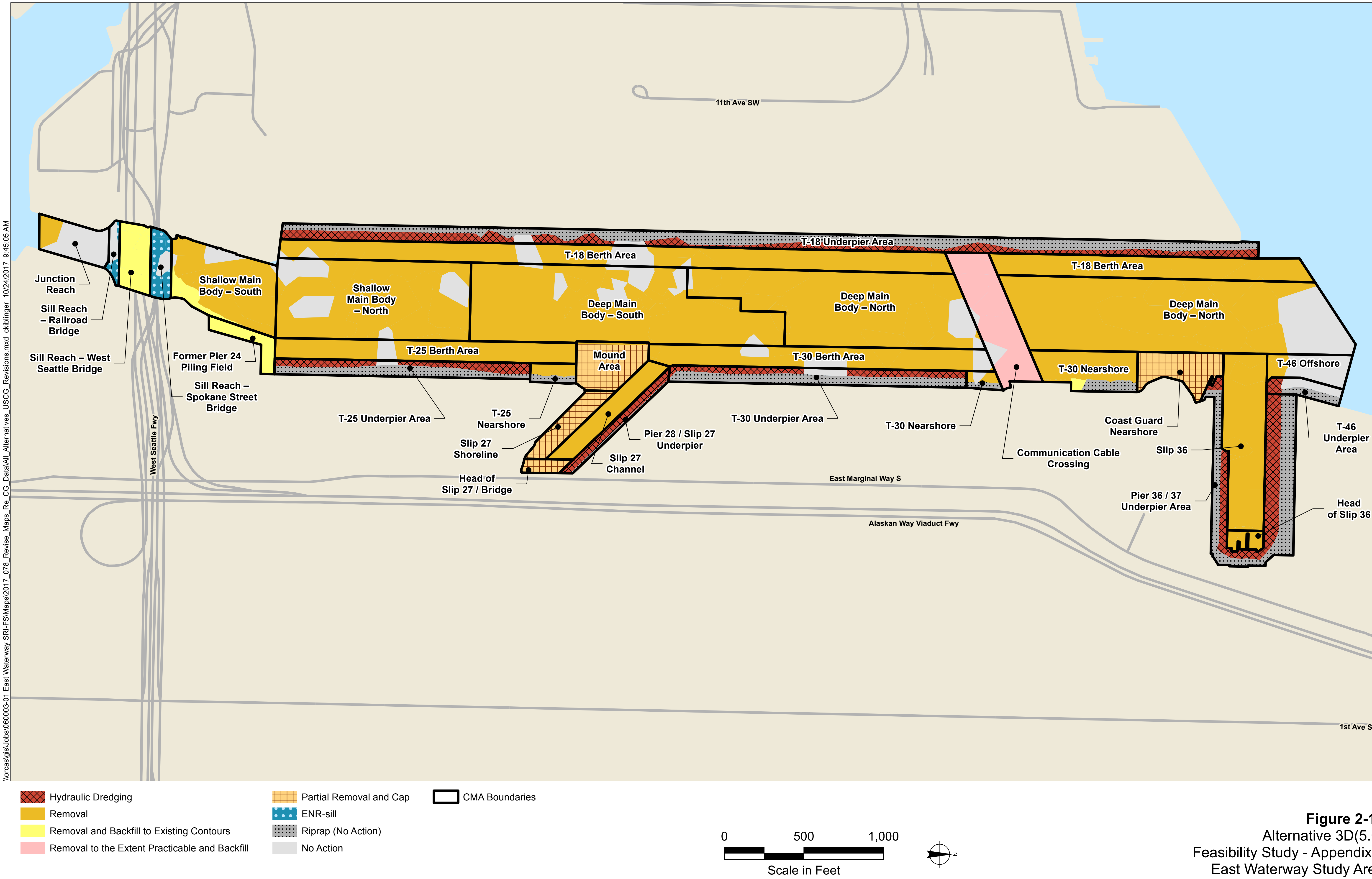

Figure 2-15
Alternative 3D(5.0)
Feasibility Study - Appendix L
East Waterway Study Area

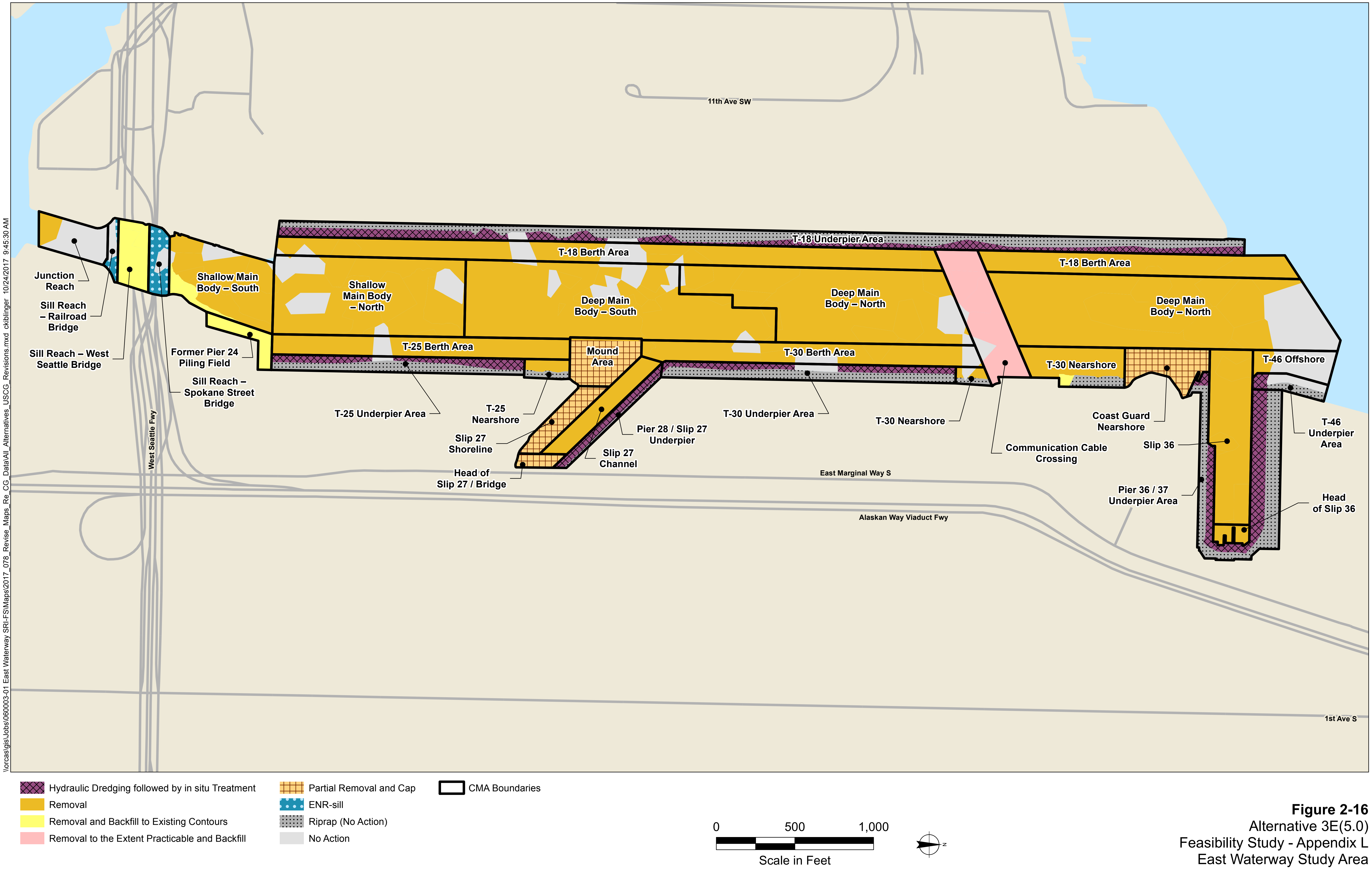

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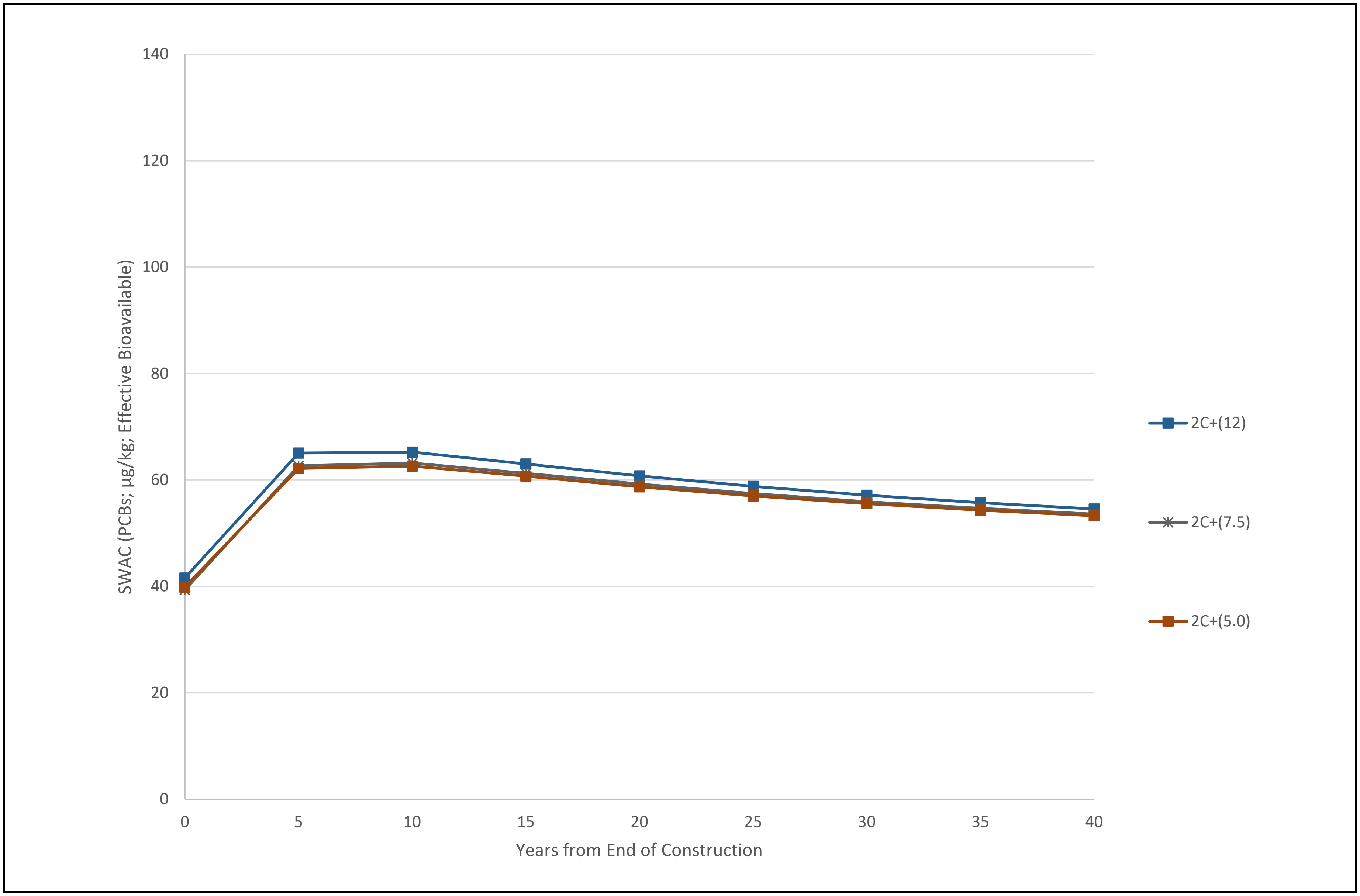
Figure 2-16
Alternative 3E(5.0)
Feasibility Study - Appendix L
East Waterway Study Area



µg/kg = microgram per kilogram
PCB = polychlorinated biphenyl
RAL = remedial action level
SWAC = spatially-weighted average concentration

Figure 3-1
Predicted Site-wide SWAC for Alternatives with Different RALs
Feasibility Study - Appendix L
East Waterway Study Area

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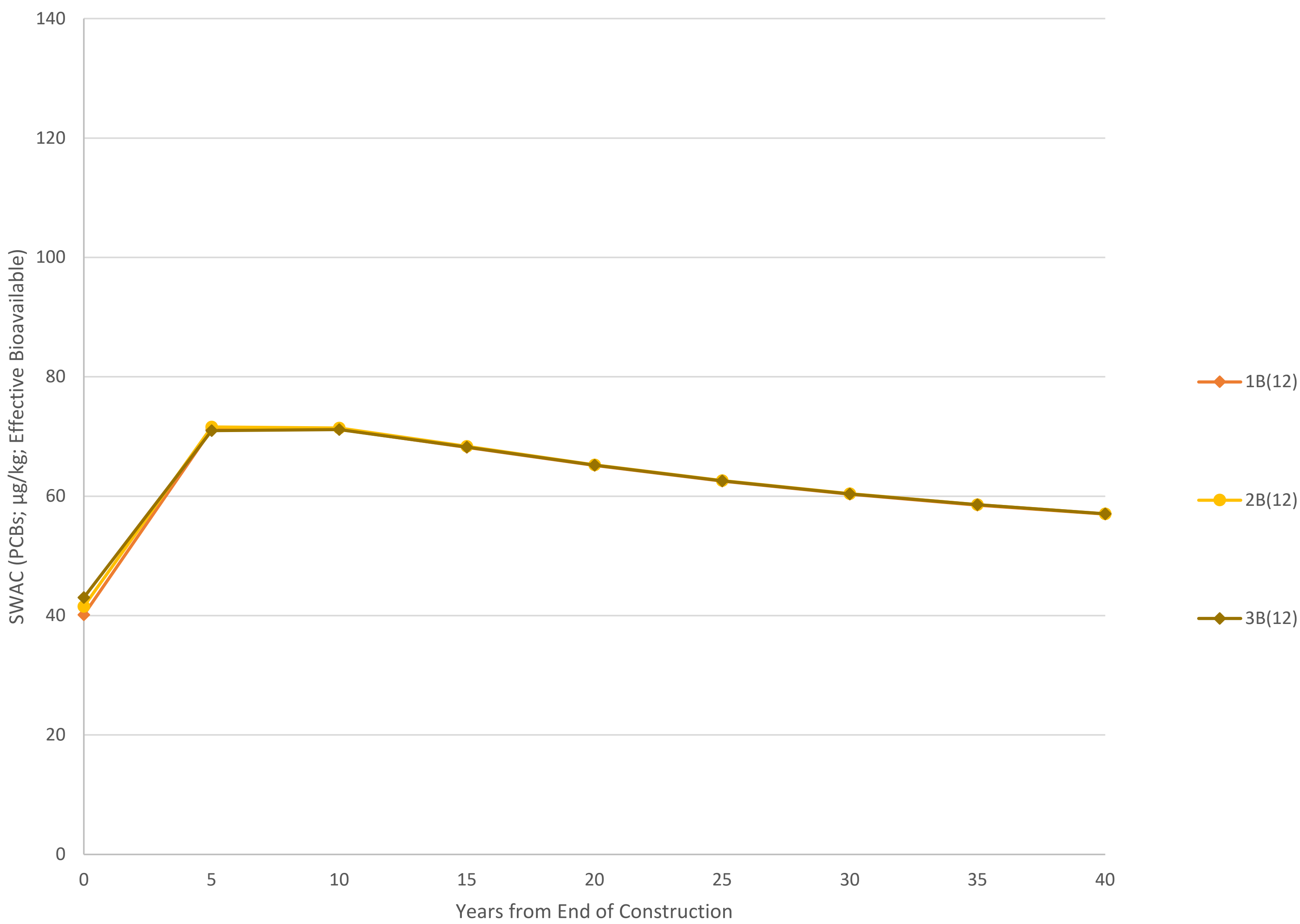
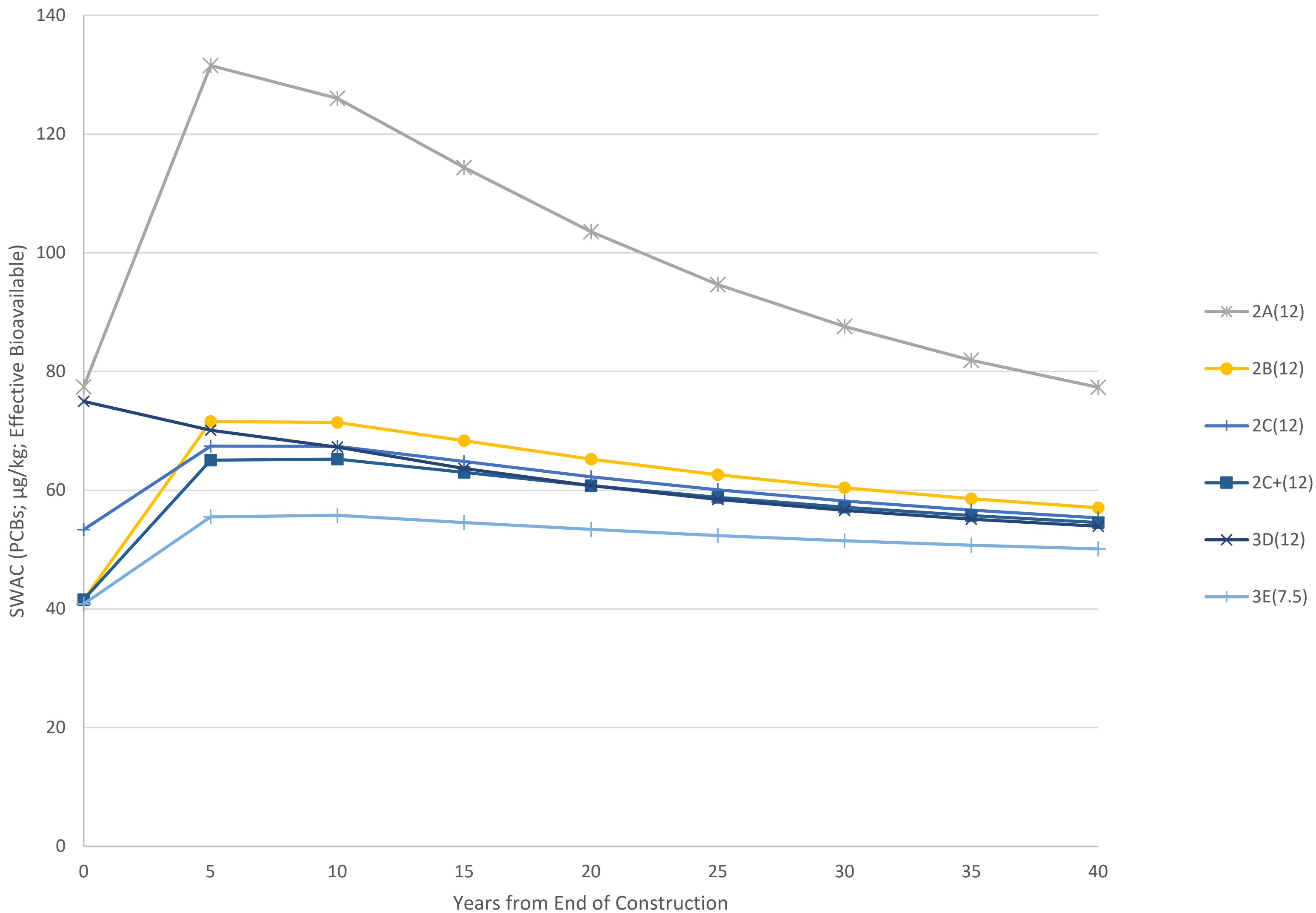


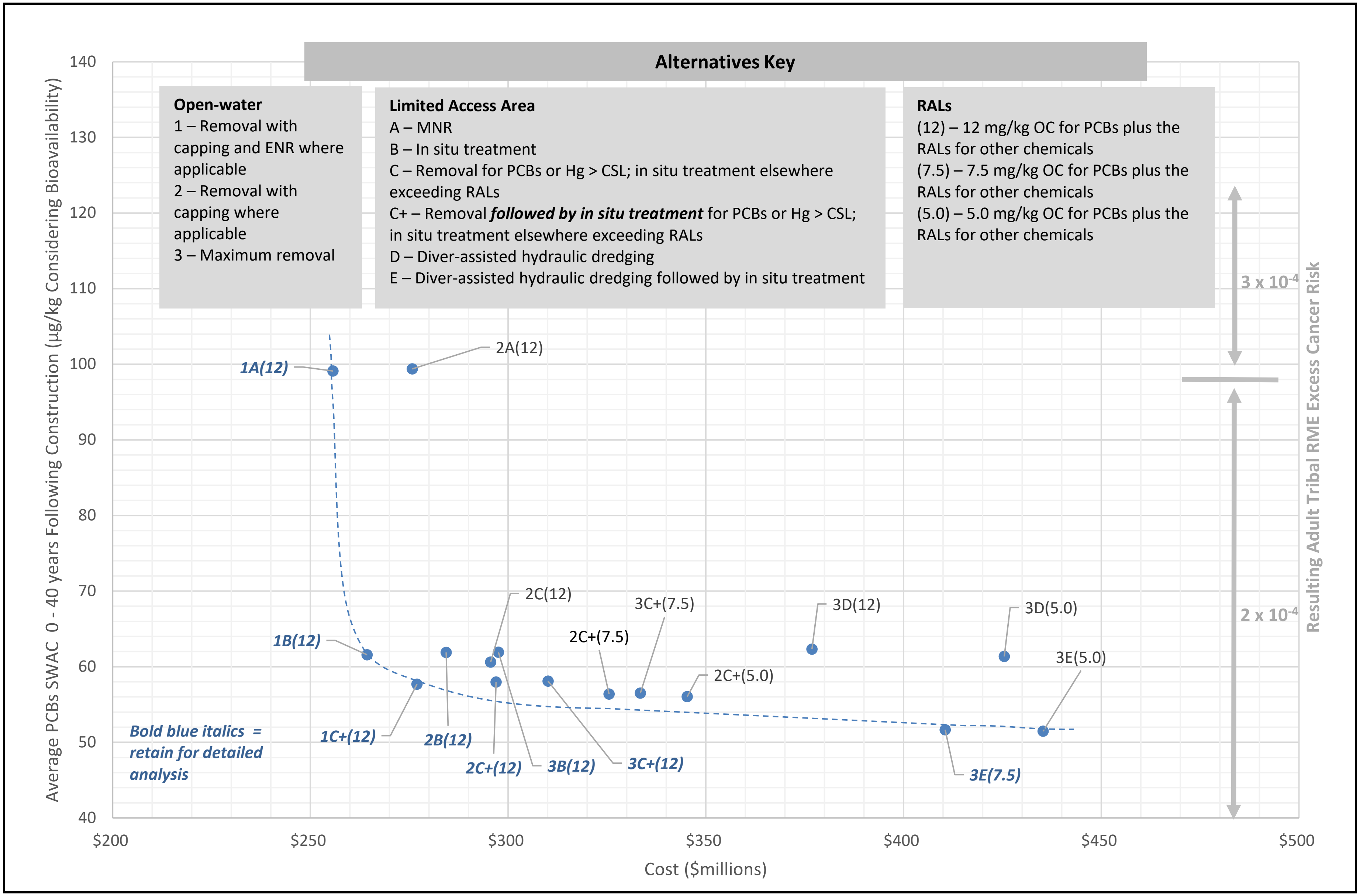
µg/kg = microgram per kilogram
PCB = polychlorinated biphenyl
SWAC = spatially-weighted average concentration

Figure 3-2
Predicted Site-wide SWAC for Alternatives with Different Open-water Technology Options
Feasibility Study - Appendix L
East Waterway Study Area



µg/kg = microgram per kilogram
PCB = polychlorinated biphenyl
SWAC = spatially-weighted average concentration

Figure 3-3
Predicted Site-wide SWAC with Different Underpier Technology Options
Feasibility Study - Appendix L
East Waterway Study Area



µg/kg = microgram per kilogram
CSL = cleanup screening level
ENR = enhanced natural recovery
Hg = mercury
mg/kg = milligram per kilogram
MNR = monitored natural recovery
OC = organic carbon
PCB = polychlorinated biphenyl
RAL = remedial action level
RME = reasonable maximum exposure
SWAC = spatially-weighted average concentration

Figure 4-1
Comparison of Alternatives
Feasibility Study - Appendix L
East Waterway Study Area